1435 Issued July 29, 1912.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN 249, PART I.

A. C. TRUE, Director.

THE STORAGE OF WATER FOR IRRIGATION PURPOSES—PART I.

EARTH-FILL DAMS

AND

HYDRAULIC-FILL DAMS.

BY

SAMUEL FORTIER,
Chief of Irrigation Investigations,

AND

F. L. BIXBY,
Irrigation Engineer.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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OFFICE OF EXPERIMENT STATIONS.

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[1] On furlough, in charge of irrigation census of Bureau of Census.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., January 25, 1912.

Sir: I have the honor to transmit herewith a report on The Storage of Water in Reservoirs for Irrigation Purposes, prepared by Samuel Fortier, chief of irrigation investigations, and F. L. Bixby, irrigation engineer, of this office.

Numerous inquiries are constantly received for information regarding the building of structures pertaining to the storage of water. The subject has been heretofore touched upon in two bulletins of this office, now exhausted.[1] The large number of reservoirs in course of construction, the larger number which it is proposed to build in the near future, and the importance of stored water in the irrigation of arid lands, warrant, it is believed, a more comprehensive treatment of the subject. In preparing this bulletin the authors have endeavored to present the best practice in building the various types of reservoir embankments and dams, and the facts given have been gleaned from a personal inspection of many of the most successful reservoirs throughout the arid region. The work will be divided into two parts, of which this is the first.

Its publication as a bulletin of this office is recommended.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

[1] U. S. Dept. Agr., Office Expt. Stas. Buls. 134, 179.

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INTRODUCTION.

Storage reservoirs of all kinds are needed to provide additional water supplies for arid lands. The snow which falls on the higher ranges and table-lands of the West melts and runs off in floods at the beginning of the irrigation season, leaving a scanty stream flow for summer use. In the Southwest the stream channels are often filled to the brim for a few hours by heavy summer rains and subsequently become dry channels. The wide fluctuation in the flow of most western streams and the irregular and intermittent character of the flow in others will, it is believed, sooner or later compel most irrigation organizations to hold back in large reservoirs a part of the wasted waters of the flood periods for use in the latter part of the irrigation season.

Small and medium-size reservoirs are as urgently needed and have a more extended use. Wherever water is raised from wells by windmills or engines a tank or small reservoir is a customary part of the plant. In the stock counties of the Rocky Mountain States there is often in the late summer season an abundance of good grass but no water. In order to utilize the forage, small reservoirs are needed to provide water for stock and to irrigate gardens and orchards.

The benefit to be derived from storage, however, is not confined to the strictly arid States. Lying east of the Rockies is a vast region of grass-covered prairie, estimated to contain 300,000,000 acres, where the rainfall is too scanty and too uncertain to produce profitable crops in dry years, and where the value of water to the farmer is being more clearly demonstrated each year. Here, too, reservoirs are needed to catch the storm waters for subsequent use.

The building of reservoirs, both large and small, has proved a most profitable investment to many owners. Late water is required for all the more valuable crops, such as alfalfa, potatoes, sugar beets, sugar-cane, and orchards. When the stream flow is short, a late summer supply for such crops usually possesses high value. Stored water can be used when it is most needed by the crops, just at the time, too,

when the natural stream flow is most deficient. It is thus possible not only to obtain larger returns from the soil but to irrigate a larger area.

Western farmers, either as individuals or as groups of individuals organized into cooperative companies, usually store water for irrigation purposes in one of four kinds of reservoirs. These are distinguished from each other by the character of the materials used in forming the dam or by some distinctive method of building. In this bulletin they have been entitled earth-fill dams, hydraulic-fill dams, rock-fill dams, and timber dams. In the largest class of reservoirs the water is usually withheld by costly masonry dams, and this type of dam has not been considered in this publication. For convenience of arrangement, earth-fill and hydraulic-fill dams have been considered together in Part I of this publication, loose rock and timber dams being taken up in Part II.

SOURCES OF WATER SUPPLY FOR RESERVOIRS.

In the varied topography of the Rocky Mountain States numerous springs abound. The majority of these are too small to be used continuously in irrigation, but when the flow of even the smallest spring is retained for a week in a water-tight reservoir it is capable of watering considerable soil. A discharge of 1 miner's inch would be considered a small spring, yet with proper storage such a flow might irrigate several acres of highly profitable land.

Springs are most common on the elevated ranges where the snowfall is heaviest. As the water emerges from the ground it is soon joined by other rivulets, which in due time form creeks. These may have sufficient volume to fill the irrigator's ditch in the freshet season, but owing to the irregularity of their flow and the necessity of storing water over night for use during the next day, reservoirs are a necessity for small creeks as well as for springs.

Wells are perhaps the most common source of supply for the smaller type of reservoirs. The water which collects in these wells, providing they are not flowing, is raised to the necessary height by means of windmills, animal power, gasoline engines, or electric motors. The discharge from the well, like that from the spring, is often too small to be applied directly to the soil. To economize in labor, water, and time it is better to store the flow over night, or until a large effective head can be had.

The main canal of an irrigation system frequently forms the source of supply where natural storage sites are accessible. It is becoming more and more common to supplement the ordinary flow of canals and streams by storage. Such reservoirs also serve an important purpose in providing water when breaks occur in the main canal above them.

Another source of supply is often produced by the extension of irrigation to the dry lands of upper benches. This is followed by an enlargement of the area of the lower lands which require drainage. This drainage water when removed may be led by gravity channels to other lands or pumped through pipes to higher levels, where it is not infrequently stored and later used to irrigate additional land.

Natural lakes are likewise used for reservoirs whenever accessibility and general fitness will permit. The common practice is to provide an outlet at a much lower level by excavating or tunneling through the rim of the lake, and to increase the depth of water stored by building an embankment around the lowest part of the shore.

In parts of the West where irrigation is a necessity there is little continuous stream flow, and the supply must be derived largely from storm water. It is of course impracticable to irrigate any large amount of land during storms, and this water can be fully utilized only by means of storage basins.

Notwithstanding the variety of sources of supply, it is true that the majority of the larger reservoirs in the West are supplied directly from streams. If these streams were of constant flow, and if crops could be grown the year through, there would be little need of storage. The results of stream measurements, however, show a very wide fluctuation, not only between different seasons of the same year but between corresponding seasons in succeeding years. The flow of a stream during 20 days in August may not equal in volume the flow of the same stream for a single day in June. So, too, the low temperatures occasioned by the high elevations of portions of the mountain States, and the cold which prevails in winter in the northern tier of the arid States, limit the crop-growing period, and, in consequence, the length of the irrigation season, to less than one-third of the year. Storage reservoirs are in such cases doubly necessary to conserve for later use vast quantities of water that would otherwise be wasted.

SELECTION OF SITE.

In selecting a site to impound water many things should be carefully considered. This is particularly true of the sites of the larger storage reservoirs, where considerable expense is frequently incurred in determining the character of the foundation, in examining the materials for the embankment, and in measuring or computing the inflow. In the smaller reservoirs the need of such careful preliminary studies is not so urgent. In this latter class the factors demanding the most attention, apart from safety, are the probable cost of construction per unit volume, the character of the materials, the water supply, and the use to which the stored water is to be put. Perhaps the chief controlling factor in the selection of such a site is

its general adaptability to store water at small expense. In arid regions in particular, men are ever on the lookout for good reservoir sites, and the fitness of these sites is usually gauged in terms of estimated cost and capacity.

But the safety of the proposed structure should not be overlooked, and this leads to a consideration of the nature of the foundation, the materials to be used in the dam, and the facilities for by-passing the flood flow of the stream through wasteways. The foundation can be best examined by digging test pits to an impervious stratum. These pits, if deep, should be elliptical in form to prevent caving and of sufficient length along the major axis to admit of benches.

Sufficient knowledge of the character of the materials for the dam may be obtained by taking samples of each formation. These samples when dried should be separated by graduated sieves into the different groups. In this way it will be possible to find out the nature of the materials as regards the weight, pore space, and general characteristics of each group.

Determining the size of the wasteway and providing for the by-passing of all waters not needed for storage are so intimately related to the question of inflow and water supply that all should be studied together.

It is true that many good sites can not be utilized on account of their inaccessibility. This is more often true of the smaller reservoirs because in the larger and costlier ones provision usually can be made to use a stream channel to convey the water from the site to the vicinity of the place of use. This, however, involves questions of the measurement and division of water among water users as well as the adjustment of transmission losses between many individuals, factors which might make the building of a small reservoir too costly or troublesome an undertaking. Accordingly, for convenience and economy, the latter should be located as near as possible to the land to be irrigated.

The reservoir should be so located as to irrigate the largest area of land possible. If it is not possible to obtain a site within the irrigable area, the farmer may be able to cooperate with the owner of the adjoining farm and the two together construct a reservoir of sufficient size to irrigate both farms. If the water supply will not permit of both areas being irrigated at once, a simple system of rotation can be mutually agreed upon and the water used in regular turns. This scheme has been carried out very successfully in the farming districts of northern Colorado, not only between individual farmers but among a number of farmers organized as a water users' association or water company. In this manner a small supply may be made to serve a much larger area than if turned directly upon the land.

Where the source of water supply is a spring, a tract of marshy ground, a pond or lake, the discharge from a well pump, or the run-off from a catchment area for flood or snow water, particularly the three last mentioned, it is clear that the reservoir site can not well be far removed from it. In the case of streams, however, there is often a choice of two methods. A part of the flow may be stored in the stream channel or it may be diverted through a pipe or canal to some locality where a favored site for a reservoir has been secured. Both of these classes of reservoirs have their strong and weak features, and the question hinges largely on the superiority of the one site or the other. If a better site can be obtained at some distance away from the stream channel it will usually pay to conduct the water to it through an open or closed conduit. Such a reservoir will cost less as a rule, will be much more secure, and will not silt up so readily. On the other hand, it is well to remember that the amount of water obtainable is gauged by the capacity of the conduit. In streams subject to high floods for short periods it is often impracticable to store much of the flood water on account of the inadequacy of the channel which conveys it from the stream to the reservoir. Again, if an open flume or canal is used the formation of ice may cause trouble in cold weather.

The area to be submerged should be carefully examined in order to discover any natural water courses or holes made by animals through which the water might escape. Soils which are very porous should be avoided unless in the smaller reservoirs some means can be employed to render the materials impervious. The materials for embankment purposes should be located near at hand in order to reduce the cost of hauling and should be of such a nature as to make a good impervious structure.

CHARACTER OF MATERIALS.

The soils and subsoils surrounding the site of any proposed earthen dam are usually taken to form the embankment. It naturally follows that a study of the materials suited to the construction of embankments leads directly to a study of soils. Of all that has been written on the subject of soils a relatively small part has any direct bearing on reservoir embankments, yet in a few particulars the relation is quite close. In all earthen embankments intended to impound water the two essentials are weight and imperviousness. The obtaining of these requisites leads to the necessity of carefully considering the size and form of the soil grains, the amount of pore space which different soils contain, the weight of a unit mass of any particular soil or combination of soil materials, and the ingredients subject to decay or to a change of form.

CLASSES OF SOILS.

The Bureau of Soils of this department classifies soils on the basis of the size of the particles or grains in seven groups ranging from fine gravel to clay in accordance with the accompanying table.[1]

Classification of soil particles.

No.	Ordinary designation.	Size of soil grains.	
		Millimeters.	Inches.
1	Fine gravel	2 to 1	1/12 to 1/25.
2	Coarse sand	1 to 0.5	1/25 to 1/50.
3	Medium sand	0.5 to 0.25	1/50 to 1/100.
4	Fine sand	0.25 to 0.1	1/100 to 1/250.
5	Very fine sand	0.1 to 0.05	1/250 to 1/500.
6	Silt	0.05 to 0.005	1/500 to 1/5000.
7	Clay	0.005 to 0.0001	1/5000 to 1/12500.

In the following discussion the above classification has been adopted. In building embankments with combinations of several of the above named classes of soil particles, perhaps the most essential thing to consider is the compactness of the mass, because the greater the compactness the greater the weight, and with some exceptions the greater the imperviousness.

COMPACTING TESTS.

For the purpose of determining the relative compactness and other properties of soils made up of varying proportions of the different sized particles, a set of experiments was carried on by one of the authors of this bulletin, the results of which are herein summarized.

The materials were first thoroughly air dried and separated by graduated sieves into the various groups. The sand and gravel were such as would be considered suitable for cement concrete. The silt was a mixture of vegetable matter and extremely fine sand while the clay was a brick fire clay. The volumes of each kind used in the different combinations are given in the following table, the latter portion of the table giving the corresponding volumes after being subjected to different treatment:

Results of tests at Logan, Utah, to determine the relative efficiency of various methods of compacting different combinations of soils.

	Volumes of original materials in cubic yards.						Volumes after treatment in cubic yards.			
	Fine gravel.	Coarse sand.	Fine sand.	Silt.	Clay.	(A) Total.	(B) Mixed but not tamped.	(C) Mixed and tamped.	(D) Mixed, moistened, and tamped.	(E) Poured into water and drained.
Combination 1	1.00	0.25	0.27		0.43	1.95	1.55	1.24	1.31	1.26
Combination 2	.90		.56	0.42		1.88	1.53	1.29	1.30	1.26
Combination 3	.90		.56		.58	2.04	1.60	1.32	1.35	1.32
Combination 4	1.00		.51	.26		1.77		1.26	1.21	1.20

[1] U. S. Dept. Agr., Div. Soils Bul. 4, p. 13; Bur. Soils, Soil Survey Field Book, 1906, pp. 16, 17.

The first five columns give the separate volumes of each class of soil used in the test.

Column A gives the total of these volumes before mixing.

Column B gives the volume of the same ingredients when thoroughly mixed dry and poured from a height of 10.2 inches.

Column C gives the volume of the same ingredients when thoroughly mixed and tamped dry in one-tenth of a foot layers.

Column D gives the volume of the same ingredients when moistened sufficiently to form a stiff paste and tamped in one-tenth of a foot layers.

Column E gives the volume of the same materials when mixed dry and poured slowly into water from a height of 10.2 inches, drained of excess water but not tamped, the measurement being taken 15 days after the experiment.

At a later period samples of some of the typical soils in the vicinity of Bozeman, Mont., were placed early in the fall in a basement laboratory and air-dried. The samples included a brown earth typical of much of the surface soil throughout the upper part of the Gallatin Valley, a black earth rich in vegetable matter and somewhat lighter, a yellow brick clay, ordinary sand, and gravel. The sand and gravel were divided by graduated sieves and the clay and earth were ground fine and sifted. The specific gravity of the particles of sand and gravel groups ranged from 2.60 to 2.72, that of the clay was 2.33, while the brown and black earths were 2.22 and 2.01, respectively. The percentage of pore space in the several groups ranged from a maximum of 55.2 in the clay to a minimum of 42.6 in the coarse gravel.

The results of the series of experiments above described are given in the following table.[1] Its arrangement is in all respects similar to the foregoing table, and the reader is referred to the explanations accompanying the former one for the meaning of the different columns. All volumes of dry, untamped materials were in this series determined by pouring from a height of 1 foot and the tamping was quite thoroughly done in layers of one-tenth of a foot.

Results of tests at Bozeman, Mont., to determine the relative efficiency of various methods of compacting different combinations of soils.

	Volumes of original materials in cubic yards.							Volumes after treatment in cubic yards.			
	Gravel.	Coarse sand.	Medium-sand.	Fine sand.	Black and brown earth.	Clay.	(A) Total.	(B) Mixed but not tamped.	(C) Mixed and tamped.	(D) Mixed, moistened, and tamped.	(E) Poured into water and drained.
Combination 1	1.00	0.25	....	0.25	....	0.50	2.00	1.63	1.38	....	1.40
Combination 2	.75	....	....	.50	0.38	......	1.63	1.31	1.09	....	1.16
Combination 3	1.00	....	0.50	......	.25	......	1.75	1.44	1.22	1.14	1.25
Combination 4	.63	....	....	.37	....	.38	1.38	1.17	.94	.91	....
Combination 5	2.00	....	.25	......	....	.75	3.00	2.38	2.00	1.88	....
Combination 6	.75	.25	.13	......	.50	......	1.63	1.25	1.11	1.03	....
Combination 7	.75	....	.25	......	.25	......	1.25	.97	.84	.77	....

[1] Part of a graduating thesis in engineering by Messrs. W. B. Freeman and J. H. Sloan, under the supervision of Samuel Fortier.

RESULTS OF TESTS SUMMARIZED.

Both series of tests bring out quite clearly the advantage to be gained in earthen dam construction by using a mixture of materials which range from coarse to fine or vice versa. In the eleven tests recorded in the two tables, the mere mixing of the materials reduced the volume on an average nearly 21 per cent. This reduction of volume produced a like reduction in pore space and a like increase in weight per unit volume.

The degree of compactness produced by pouring the materials loosely from a height of 12 inches into water and allowing the mass to drain will in all probability equal that produced by any of the ordinary processes used in earthen dam construction. It is true that the average of the above tests gives a slight advantage in favor of the tamping process; yet it must be noted that the tamping in the experiments was done by hand in a vessel in one-tenth of a foot layers, while in practice the materials are compacted by the passage of teams, the feet of animals, or the pressure of rollers. None of these methods, it is believed, would be as effective as the hand tamping employed. The hydraulic method, however, gives the same degree of compactness whether employed on a large or small scale.

The weight of a unit mass of different grades of soils such as were combined in the preceding tests depends on the character of the materials selected and the compactness of the mass when subjected to any one of the processes described. For example, in test No. 1 of the second series it was found that the materials when separated in the proportions named weighed 83.7 pounds per cubic foot; when mixed their weight was 102.7 pounds; when mixed and tamped, 121.4 pounds; and when poured into water 119.6 pounds. The greatest weight was found in test No. 7 after the ingredients selected had been mixed, moistened, and tamped in one-tenth foot layers. The weight was then 137.3 pounds per cubic foot. It is well to note that the figure just given represents the respective weights of the air-dry material. None of the weight of the water which was added is included.

It is interesting to compare the weights just given for the various combinations and mixtures with the weights of similar volumes of each class alone. The gravel used in these same tests when poured from a height of 12 inches weighed in this loose form 90.6 pounds per cubic foot, the sand 82.3 pounds, the black and brown earth 64.5 pounds, and the clay 65.2 pounds. The results show that it is possible to take such materials and so combine and consolidate them in a reservoir embankment that their weight, exclusive of that of any water added, may be 120 to 135 pounds per cubic foot.

When used alone there are serious objections to any one of the soil classes above named for building reservoir embankments. The

weight and stability of gravel and the fact that it is affected but little by the action of frost, drought, or moisture are points in its favor. It is lacking, however, in one essential feature, viz, water tightness. Its large particles, inclosing 35 to 45 per cent of open space, would permit considerable volumes of water to percolate through and for this reason it can not be used alone. An embankment of sand would be more impervious but less stable and more affected by any excess of moisture. Earth containing a high percentage of organic matter might make an impervious embankment, but the necessary weight and stability would be wanting. The same is true of all clays. Clay is the most impervious material and for this reason it is often used for core walls or for certain parts of a dam. However, its tendency to swell and slump when partially saturated and to shrink and crack when dry renders it unsafe when used for the entire structure.

Clay concrete: The objections to any one class of materials when used alone disappear when the classes are properly combined. An ideal combination has been termed clay concrete.[1] In this the open or pore space in the sand is filled with silt and clay and the open space in the gravel is filled with sand, silt, and clay. In so mixing these materials it is possible to reduce the pore space to less than 13 per cent of the total volume. Clay concrete is more stable and heavier than gravel and nearly as impervious as the clays. It possesses all the desirable features of each class of materials when used separately with few of their objectionable features.

While it is true that an ideal combination of the kind just referred to is seldom found to exist in a natural condition on the site of a proposed dam, yet a knowledge of what are suitable proportions of gravel, sand, silt, and clay is necessary in order that sites may be selected with a view to this end. Moreover, with a knowledge of suitable mixtures, it will usually be possible for one to secure sufficient quantities of gravel, sand, fine earth or clay near enough to any site to make an entirely satisfactory embankment.

The question of economy will naturally be given great weight in deciding what materials to use. It would be useless, for example, to recommend materials that could not be cheaply and readily secured. The ease and dispatch with which earth can be handled sometimes outweighs all other considerations, so that many prefer to increase the dimensions of the embankment and use an extra quantity of material rather than to go to the expense of obtaining a more suitable mixture at greater cost.

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[1] See The Storage of Water in Earthen Reservoirs, by Samuel Fortier (Trans. Canada Soc. Civ. Engin., 10 (1896), pt. 2, p. 152).

FOUNDATIONS.

CUT-OFF WALLS.

The embankment should be laid on firm and reasonably dry ground. While it may be feasible to remove soft and mucky soil and drain the subsoil, it is seldom advisable to adopt a site where this is nesessary. The foundations for ordinary embankments without masonry core walls are usually laid in the following manner: The entire area of the foundation is first plowed; and all sods, plants, or other materials liable to decay removed to the outer toe of the slope. A trench is then dug along the center line of the proposed embankment. This trench should be not less than 4 feet wide in the smaller nor less than 8 feet wide in the larger dams, while in depth it should extend downward until hardpan, bedrock, or other safe, firm stratum which offers a water-tight bond, is reached. It should extend well up on the hillsides at the ends of the proposed dam as shown in figure 6, page 34. The trench is then filled two-thirds full of water and good puddling material dumped into it until brought to a level with the surface. The site of the foundation is again ridged deeply by a grading plow and the base of the embankment placed upon it.

The cut-off wall of the foundation is frequently continued through the embankment as a core wall. The most practical form of doing this is considered under "Embankments," pages 23, 24.

To make a more perfect bond between the cut-off wall and bedrock, a concrete wall several feet in height is sometimes built in the bottom of the trench. In the case of the Pilarcitos Dam of the Spring Valley Water Co., San Francisco (fig. 1), this precaution was taken. The trench in this case was 46 feet deep and 12 feet wide. The concrete wall in the center of its bottom was 6 feet high and 3 feet wide. The surface of the rock was roughened to make the concrete adhere properly.

Another method sometimes used in the construction of earthen cut-off walls is to deposit the selected clay material in the trench in thin layers, not exceeding 3 or 4 inches. Each layer is then thoroughly spaded, slightly watered, and tightly rammed until the surface of the prepared base of the dam is reached. This puddle is made so stiff that a horse walking over it will not sink his hoof more than 2 inches. For continuation of puddle core in embankment, see "Embankments," page 24. The above is the practice of the Spring Valley Water Co.[1]

PREPARATION OF SURFACE OF SITE.

Occasionally, where the subsoil and underlying strata have been found to be of especially firm and impervious material, the cut-off wall has been dispensed with. The Twin Lakes Dam Reservoir

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[1] Herrmann Schussler. The Water Supply of San Francisco, 1906, p. 45.

No. 2, located 13 miles south of Leadville, Colo., on Lake Creek, is a successful example of this type of construction. No other provision than thoroughly clearing and plowing of the site was made to secure a good bond in the foundation, yet very little seepage has occurred. This dam is 30 feet maximum height, 400 feet long, with a 3 to 1 slope on the upstream and a 2 to 1 on the downstream side. The Skeel Reservoir near Denver is also of this type. There has been no seepage through the dam.

In the case of the Sugar Loaf Reservoir Dam, located about 5 miles west of Leadville, Colo., also on Lake Creek, the dam site was

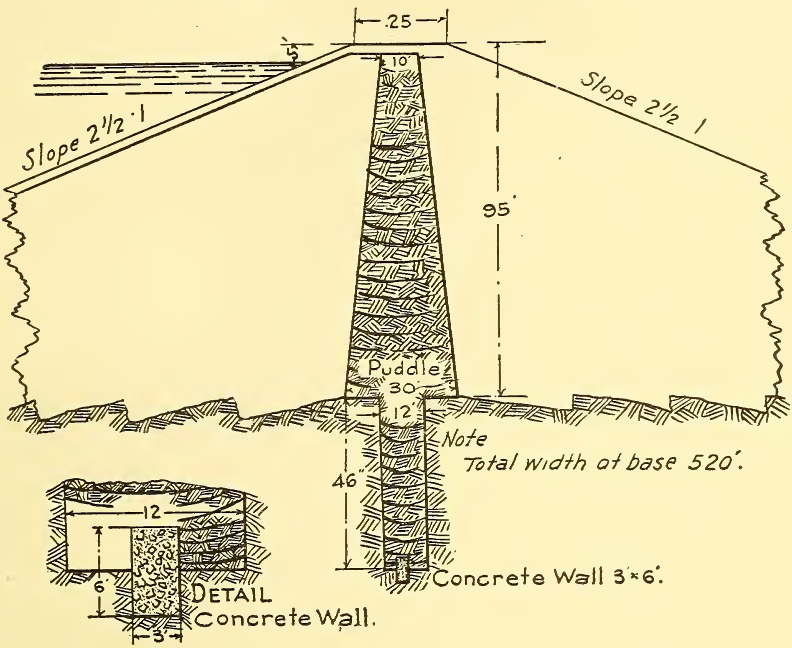

Fig. 1.—Section of Pillarcitos Dam, showing puddle core and concrete wall in bottom of trench.

overgrown with willows and other shrubs. Care was taken to grub thoroughly, the top soil having been skimmed off by light plowing and slip scrapers. Mucky soil was also removed and the surface was then benched and furrowed. There has been very slight evidence of seepage below the dam.

It is a very good plan, where plowing and clearing alone are depended upon, to use a subsoiler in every third or fourth furrow longitudinally with the dam. This practice was followed with good results in the building of the Boulder and Laramie County Reservoir Dam, located 3 miles south of Berthoud, Colo.

The removal of all large, loose stones, especially on the upstream half of the foundation surface, is also considered advisable. The

builders of the Hatchtown Dam, located on a branch of the Sevier River, Garfield County, Utah, cleared the entire area of all large stones as well as brush and débris of all kinds; it was then deep plowed, harrowed, and again cleared of all large stones. This dam, however, was not dependent upon plowing alone for a bond; it is provided with a large puddle trench extending down to hardpan and the length of the dam.

The enlargement of an existing dam demands the same care in bonding the new with the old work as in the case where an entire new dam is constructed. The Miller & Harmon Reservoir Dam No. 1, located in Boulder County, Colo., is an example of this. All surface soil, roots, and vegetable matter were removed from the base of the dam and from the surface of the old dam before new work was commenced. The character of the subsoil was carefully examined by means of borings and test pits and was found to consist of sandy clay quite impervious to water and generally free from sand pockets. It was therefore deemed unnecessary to excavate below the surface for the foundation.

BORINGS AND TEST PITS.

The use of such borings and test pits to determine the nature of the materials beneath the natural surface of the site has already been touched upon (see "Selection of site" pp. 12, 13) and is strongly urged in every case of dam building. The care exercised by the engineers of the Reclamation Service may well serve as a guide here. The building of the Deer Flat Reservoir of the Boise project, 4 miles west of Nampa, Idaho, may be given as an instance. This reservoir contains an area of 9,250 acres, with a total capacity of 186,000 acre-feet. Two dams have been constructed on similar lines, the Lower Embankment having a maximum height of 40 feet and a length of 7,200 feet, and the Upper Embankment having a maximum height of 70 feet and a total length of 4,000 feet. Careful investigations were made of the foundations at the sites of the respective dams and also over the entire area of the reservoir. At first churn drills were used, but this process was slow and unsatisfactory, and test pits were finally resorted to. Twenty test pits 12 to 38 feet deep were dug with pick and shovel in the vicinity of the proposed dam site and on the area covered by the dam. There were no gravel beds of any sort exposed in the basin, and at no point examined was there less than 4 feet of soil and hardpan above any such formation. In some of the pits dug it was necessary to use curbing or shoring, especially on the hilltop where sand and gravel were encountered. No curbing was used in the holes in the flat or on the axis of either dam. Good, compact material was found in all the latter holes.

Where the upper surface of the bed rock is found to be badly fissured, either slate or shale formation, an excavation should be

made below this to solid rock. The necessity for extreme care on this point is illustrated in the failure March 11, 1910, of the Jumbo Dam of the Julesburg irrigation district, located 6 miles north of Sedgwick, Colo. A complete report of its failure is given by State engineer Charles W. Comstock.[1] According to the opinion of George T. Prince, consulting engineer, the main cause of the failure of this dam was due to the water finding its way from the reservoir through an exceedingly porous and dangerous stratification of rock which underlaid the foundation of the dam. Not enough water was liberated at the lower end of the dam to prevent an upward pressure throughout the rock mass at a depth of 30 feet or more below the base of the dam. The point of least resistance was beneath the lower toe, where the rock mass was lifted from its bed and carried downstream by the torrent of water.

LOCATION OF PUDDLE TRENCHES IN FOUNDATION.

Where there is but one puddle trench the center line of the foundation (parallel to the axis of the dam), or slightly above it, is considered a safe location. The Hatchtown Dam, already mentioned; the Jones & Davidson Dam, 50 miles south of Dillon, Mont., on Alkali Creek; the Esler Lake Dam, 25 miles northwest of the same town on Rattlesnake Creek; the Pilarcitos Dam of the Spring Valley Water Co.; the Lake Theodore Dam of Clipper Gap, Cal.; and numerous others, may be cited as examples of this type.

Occasionally a series of trenches is employed instead of the one centrally located. The Sevier Bridge Dam, Millard County, Utah, illustrates this type. It has four trenches cut at right angles to the axis of the stream—one at the upper toe, 12 feet wide; one at the lower toe, 4 feet wide; and two equally spaced through the central area, each 4 feet wide. Each of these was dug to hard material and filled with puddle clay. The Mammoth Dam, Sanpete County, Utah, is also of this type. Few, if any, objections other than that of cost can be made to the use of two or more cut-off walls at the base of embankments. These, however, should be located in the upper half of the base. To introduce one or more in the lower half is a source of weakness rather than of strength, since any water which percolates more than half way through an embankment should be allowed to escape.

EMBANKMENTS.

The belief is prevalent among laymen and engineers inexperienced in this kind of work that any country road foreman who is familiar with the handling of earth is qualified to superintend the building of earthen dams. They fail to understand the difference between an

[1] Bien. Rpt. State Engin. Colo., 15 (1909–10), pp. 104–111.

embankment capable of withstanding a load and one compact and stable enough to retain water. In highways or railroad fills little if any attention is given to packing the materials. The fill, when completed, is nearly as porous as the soils and subsoils of which it is composed. The diversity of opinions among engineers on this subject is remarkable and difficult to explain. The differences in the kind and quality of the materials used may partially account for it, but apart from this one is forced to conclude that the opinions held by many engineers regarding the best way to design and construct earthen embankments to impound water are erroneous. For any given case the problem is: To store with safety to life and property a certain volume of water on a particular site within walls of earth. The task seems easy and simple, but in its design and execution the plans and specifications from a dozen or more competent engineers would show great dissimilarities. One engineer would be willing to incur considerable expense in procuring clay for the entire embankment; another would use clay only as a center core; while a third would reject it as the most treacherous material in existence for that class of work, and would build a homogeneous wall of a mixture of fine and coarse materials. Some would specify that the materials be packed dry, others that they be dampened, while some would call for an abundance of water.[1]

COMMON TYPES OF EARTHEN EMBANKMENTS.

The most common and approved type of earthen embankments will come under one of the following general classes:

(1) Those which have a puddled core wall near the center of the embankment.

(2) Those of a more or less homogeneous earth type, which are built by depositing the materials in thin layers which are subsequently moistened and compacted.

(3) Those which have a concrete or masonry core wall near the center of the embankment.

(4) Those built by sluicing the materials into place.

There are, of course various modifications and combinations of all the above types. For instance, even where the puddled core type is adopted, it is well to exercise the same care in depositing the materials on the upper half of the embankment outside the core in layers and in moistening and compacting. It is well, also, in every case to place the more select and impervious material on the upstream half and the coarser, more porous, material on the downstream half of the embankment.

A somewhat more costly type than any of the above for reservoirs of small capacity is common in southern California and to a less extent

[1] See The Storage of Water in Earthen Reservoirs, by Samuel Fortier (Trans. Canad. Soc. Civ. Engin., 10 (1896), pt. 2, p. 156).

in other parts of the arid region. In this type less dependence is placed upon the embankment and more upon a plain or reenforced concrete lining.

Another variation from the common types is where the entire upstream face of the dam is puddled to a depth of 15 or 20 feet, the central core wall being in such cases usually omitted. This is not common, however. The Monument Creek Dam, 15 miles north of Colorado Springs, 40 feet in height, is of this type. The inner face is covered with a clay puddled wall having a horizontal thickness of 50 feet at the base and 10 feet at the top. This puddle wall is carried down to bed rock in a trench 14 feet deep at the inner toe of the dam, the minimum width being 5 feet. Over the puddle wall is laid a riprap of stone placed by hand with great care.

The advocates of a masonry or concrete core wall differ greatly in regard to the proper size and style to be used and the purposes served thereby. This subject will be discussed further under the appropriate head.

The choice of the type of embankment to use in any particular case will depend upon local conditions and the character of the materials available. Anyone who has had previous experience in this line will easily determine the most practical type to adopt. The first two of the four general classes named will be taken up at this point.

THE PUDDLE-CORE TYPE.

The water used for puddling may be obtained from a spring or creek and conveyed by gravity or it may be pumped from the bed of the stream. In some cases a temporary dam is built farther up the stream to store sufficient water for this purpose, and in not a few instances it is hauled in wagons. From whatever source it comes, or in whatever way it is secured, it should always be regarded as a necessary part in building earthen dams. The use of dry earth for such structures, no matter how generous the dimensions or how firm the packing, is not to be recommended.

An excellent and practical method of building the core wall is by use of a puddling canal which intersects the embankment at a right angle to the flow of the stream, either at the center line or slightly toward the upstream face. This canal is begun as an excavated trench in the foundation, as described under a previous heading, and continued through the middle of the embankment as construction progresses. The proper form to maintain is shown in figure 2.[1]

It will be noted that each half of the embankment is given a slight pitch toward the canal, which is kept nearly full of water, and the selected puddling material is dumped into it. The sloping of the layers of earth toward the center is preferable to having them horizon-

[1] Redrawn from Trans. Canad. Soc. Civ. Engin., 10 (1896), pt. 2, p. 156.

tal, as this concave form not only retains the canal water but permits a flooding of the surface at the close of each day's work.

The puddling material should consist of a mixture of gravel, sand, and silt or clay. The adaptability of these materials for this purpose and the relative efficiency of the various means of compacting them, such as tamping or dumping into water from a height, are fully discussed under the head "Character of material," pages 13–17.

The dam for the distributing reservoir of Ogden City, Utah, was built in the manner above described; also the San Andres Dam, California. The trench of the former was dug along the center line of the embankment 4 to 6 feet wide and 6 feet deep. The trench of the latter was 45 feet deep and 20 feet wide, and extended the same width through the dam. In general, it may be said of this method that when about 20 per cent of clay is mixed with sand and gravel a stable impervious core wall can be built.

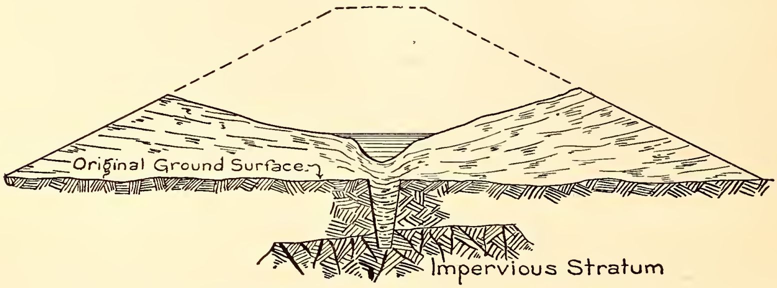

FIG. 2.—Building a core wall by the use of a puddling canal.

If the material is chiefly clay, however, it is best applied for a core wall in thin layers, which are afterwards moistened and compacted. The Spring Valley Water Co., of San Francisco, uses the latter method in the construction of its core walls. The material is deposited in very thin layers, each layer being slightly moistened and thoroughly spaded and tamped, as has been described under the head "Foundations," page 18.

THE HOMOGENEOUS EARTH TYPE.

The necessity of securing a water supply is as urgent in this type of dam as in the former case. If the work be done in rainy weather the material, as it comes from the pit, may be sufficiently moist to pack well, but under ordinary conditions it will need to be moistened. The securing of a firm bond to the underlying strata of earth or rock, the clearing away of all débris, and the plowing of the dam site have been fully discussed under the title "Foundations," pages 18–20.

The site having been prepared as therein described, the finer and more impervious material is used near the upstream toe of the dam; the coarser and more porous material near the downstream toe. It is

spread over the entire surface in thin layers, rock pickers being constantly at work where necessary to remove all roots and brush, and all stones weighing in the neighborhood of 5 pounds or more.

Practice differs in the matter of the sloping of the layers. While all agree that they should be level from end to end of the dam, that is, at right angles to the flow of the stream, opinions differ on the slope to be given up or down stream. In some cases a slight fall is given to both the up and the down stream surface toward the center; in others the layers are sloped toward the water surface, and in still others the layers of the upstream half are pitched toward the upstream toe, while those of the downstream half are pitched toward the downstream toe. The object of giving these slopes is not only for convenience in flushing, if desired, at the end of the day's work, but to guard against slumping and to prevent the percolation of water along the surfaces when horizontal layers are used.

The usual practice as to the depth for the layers is 4 to 10 inches. While successful structures have been built without any attempt to deposit the material in layers, it is also true that some disastrous failures have been attributed to a disregard of due caution here. In the opinion of J. W. Johnson, deputy State engineer of Colorado,[1] the failure of the Jumbo Reservoir, to which reference has already been made, was caused not only by seepage through the porous sandstone formation described, but by seepage through the lower part of the fill of the dam as well. The specifications for this dam contained the following inadequate requirement: "Earth shall be placed in the dam in level layers which must not have a thickness of more than 4 feet." With the exception of a condition for the removal of all "large clods or frozen chunks" this was the only clause of the specifications on embankment construction.

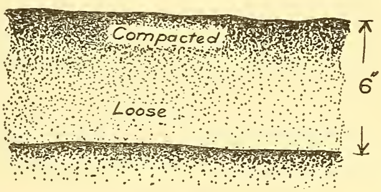

FIG. 3.—Illustrates uneven compacting produced by ordinary rolling of layers.

The passage of teams and implements and rollers back and forth over the top of an embankment that is being built does not in itself insure uniform packing for some kinds of materials. When the layers are consolidated in this way the top part of each receives a thorough packing and puddling but the lower two-thirds may receive very little. This condition results in a more or less stratified embankment (fig. 3). To remedy this defect, the trampling of sheep, goats, horses, and other stock has been found effective. Each layer of earth is first moistened to the right consistency and then the repeated passage of a band of stock over it mixes, puddles, and compacts it in a manner which can not be excelled.

[1] Bien. Rpt. State Engin. Colo., 15 (1909-10), p. 105.

When animals are not available or can not be used, each layer may be mixed and compacted by grooved rollers. The grooves should penetrate each layer, since the mixing is as important as the packing. A. F. Parker, city engineer of Ogden, Utah, in building a distributary reservoir for the city, made use of a good substitute for grooved rollers in the way of a wagon fitted up with an extra pair of wheels and having the three axles of different lengths so that each of the six wheels made a separate groove. The wagon was weighted with sacks filled with gravel. When ordinary rollers are used they should weigh at least 1 ton per linear foot of roller. Even where heavy rollers are used to compact the layers, it is a good plan to have the loaded carts and wagons which are used in transporting material travel longitudinally over the dam while still loaded, cutting their wheels through the slightly watered face of the dump, thus thoroughly consolidating the new layer with the former one. The Spring Valley Water Co.[1], in the construction of its embankments, seems to rely a good deal upon this method, although it also rolls the finished layer with a 3-ton roller, having a face of not more than 3 feet in width. Where the roller can not reach, at the ends of the dam, first-class hand ramming is employed, insuring a water-tight seal with the slope of the hill. The layers, which do not exceed 10 inches in thickness at one time, pitch about 1 foot in 40 toward the center line of the dam.

It is a good idea to roughen the surface of each layer by light disking before depositing the succeeding layer. The specifications for the Utah State Land Board for the building of the Hatchtown Dam, Garfield County, contained a proviso to this effect. They also stipulated that the upstream toe should be built of the finer material, while the downstream toe should consist of all the coarser material loosened in obtaining material for the core or the upstream toe, and any other coarse material available. In this embankment the layers of the upstream toe did not exceed 6 inches in thickness and sloped toward the upstream edge, while those of the downstream half might be up to 1 foot in thickness and sloped toward the downstream edge approximately 1 to 10. The surface of each layer was leveled by means of harrows or levelers and rolled with a roller weighing 1 ton or more per foot of length.

A point is sometimes made of dumping the earth in rows by dump wagons while they are in motion. These rows are generally parallel with the axis of the dam, except at the ends where the wagons make the turns. This was done by the builders of the Tabeaud Dam, located 8 miles above Jackson, Amador County, Cal. Unlike the last dam mentioned, the top of this one was kept basin shaped during construction, with a slope of about 1 in 25 from the sides to the center.

[1] Hermann Schussler. The Water Supply of San Francisco, 1906, p. 45.

The specifications required the body of the dam to be constructed in 6-inch layers up to a height of 60 feet and 8-inch layers above that elevation. The rows were then leveled by 6-horse road graders and the material was harrowed and rolled, being sprinkled by water wagons and by hose and nozzle as required. While heavy rollers were used, the passing wagons when loaded were found to compact the earth more thoroughly than the rollers. The usual care was taken to remove all roots, stones, etc.

The Skeel Reservoir Dam previously mentioned is an interesting example of the homogeneous type without a puddle core where no attempt was made to build the embankment in layers. It was built in 1890 and enlarged in 1901, and has a maximum height of 35 feet. The material was mostly wet when put in place and formed a very compact fill. Twenty to thirty scrapers were employed in depositing the earth, and the tramping of the horses' hoofs was sufficient to secure a homogeneous mass so that seepage water has never made its way to the lower slope of the dam. While the procedure followed in this case may prove successful under the most favorable conditions, it is not to be recommended as a guide.

It will be noted from the foregoing descriptions that both wagons and scrapers are used to transport material to the dam site in ordinary cases. In former years the bulk of the earth used in the smaller dams was handled by 2-horse slip scrapers. While these implements are still used, they have been to a large extent superseded by the 4-horse Fresno scraper which is much more economical. The use of wheel scrapers, dump wagons, steam shovels, and engines is more common in the construction of the larger embankments. In Plate I, figure 1, is shown a convenient and practical method of loading wagons by dumping the material from scrapers upon a trapdoor.

COST OF EARTH WORK.

The price of labor and commodities is so constantly changing, and there are so many varying conditions pertaining to the construction of embankments in different localities that it is difficult to give cost data which will be of general applicability to all cases. Some of the factors which will influence cost are the accessibility of the site, the location of suitable materials such as gravel and clay with reference to the site, the extent and character of the excavation to be made, and the size of the structure. The following figures pertaining to the cost of embankments on two of the larger projects in the West are given more to show the relative values of the different items that go into earth-fill construction than to serve as a standard for all conditions.

In the building of the Lower Embankment of the Boise project the following analysis of contractor's cost is given by the Recla-

mation Service, all figures being on the cubic yard unit basis. Two methods were employed in excavating and transporting materials, grading machines and teams being used for one part of the work, while steam shovels and cars running upon tracks were used in the balance. The cost under each method is given separately.

The grading machines and teams moved 586,278 cubic yards, the cost being divided as follows: Interest on investment 1.14 cents, plant depreciation 1.76 cents, superintendence 0.83 cent, repairs 0.8 cent, excavating 3.67 cents, hauling 7.83 cents, spreading 0.83 cent, sprinkling 1.22 cents, rolling 0.33 cent, freight and freighting 0.84 cent, drain 0.35 cent, clearing right of way, 0.13 cent, total 19.73 cents.

The steam shovels and cars moved 85,637 cubic yards, the cost being divided as follows: Interest on investment 1.16 cents, plant depreciation 4.74 cents, superintendence 1.49 cents, repairs 2.22 cents, excavating 8.27 cents, hauling 9.13 cents, spreading 1.06 cents, sprinkling 1.68 cents, rolling 0.34 cent, freighting 0.59 cent, total 30.65 cents. The average cost of all material placed in the earth body by both methods was 21.1 cents per cubic yard. The contractor's bid was 24 cents per cubic yard.

The material for the earth body of the dam was hauled mostly from the borrow pits located above and below the dam and extending parallel thereto throughout its entire length of more than 7,000 feet. A berm 40 feet in width was left beyond the upper and lower toes of the slope. The average depth of these borrow pits was 1.3 and 3.5 feet, respectively, and their widths about 500 feet. The average length of haul was 400 to 500 feet. The earth removed by the grading machines was hauled in 3-horse dump wagons, while the material excavated by steam shovels was hauled by cars. (Pl. I, fig. 2.)

In the first method of excavation there were three elevating graders, two 22-horsepower traction engines, and 40 dump wagons with horses. Two of the graders were in use continuously, drawn by the traction engines when the material was moist and fairly firm, and by horses when the material was dry and loose. Sixteen to 18 horses were used on a grader. The material was a sandy loam containing considerable clay to a depth of about 18 inches. Below this depth it was indurated earth (hardpan) containing a large percentage of clay. This was extremely difficult to loosen and required 8 to 10 horses on a plow. It loosened very readily, however, when water was applied, and it was the practice of the contractor to turn water into the borrow pits after each plowing. This greatly facilitated the excavation besides keeping down the dust. The output per grader varied from 575 to 725 cubic yards per day under favorable conditions. The hauling of this earth was done by teams and dump wagons. Two road graders were employed in spreading, each

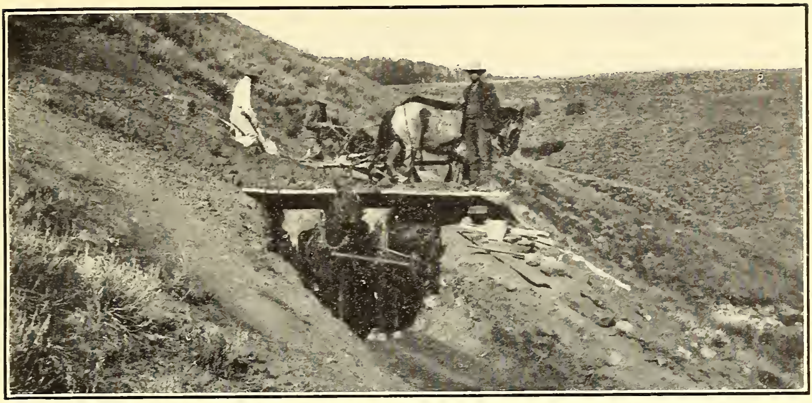

FIG. 1.—USE OF TRAP DOORS IN LOADING WAGONS.

FIG. 2.—CARS DUMPING MATERIAL ON EMBANKMENT, BOISE PROJECT, U. S. RECLAMATION SERVICE, IDAHO.

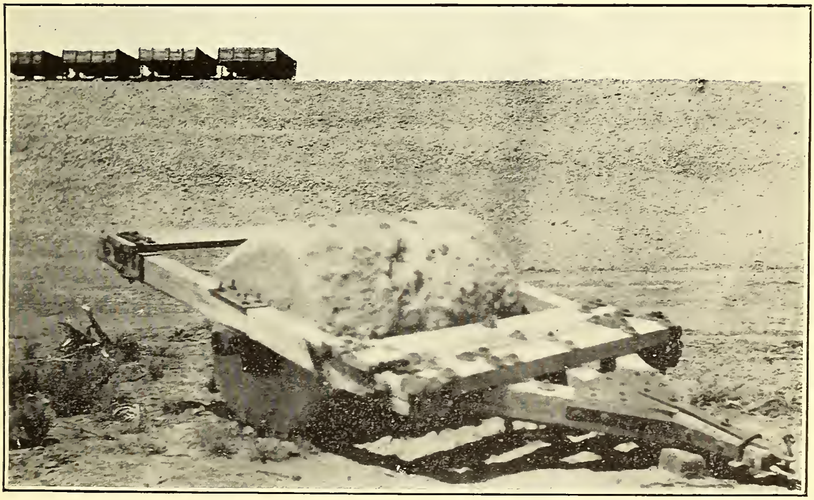

FIG. 3.—CONCRETE ROLLER USED ON BOISE PROJECT, IDAHO.

requiring four horses. Water for sprinkling was pumped from a small reservoir located on the upper berm and supplied from an irrigation ditch near by. The pumping was done by means of a gasoline engine and a centrifugal pump to standpipes on top of the work. Four 800-gallon sprinklers were used in this work, each requiring four horses. The amount of water represented about 12 to 16 per cent of the volume of the material to which it was applied. Two rollers were used in connection with the work, each requiring six horses. The rollers were constructed by the contractor on the ground and were made of concrete (Pl. I, fig. 3), each being 5 feet in length and weighed a little more than 1 ton per linear foot.

In the second method of excavation, which was used mainly in moving the gravel and coarser material for the face and back of the embankment, three steam shovels were used. Material which was not suitable for placing on the outside slopes of the dam was placed in the central portion. This material was hauled by cars, the average haul being about 3,600 feet. The cost of this haul was a little over 1 cent per yard more than the cost of hauling by wagon. A 60-ton, 2-yard dipper shovel was the one used mostly on this work. Two 14-ton locomotives, both old, ten 4-yard dump cars, and twenty-two 3-yard dump cars with $1\frac{1}{2}$ miles of rails were used. The earth was loaded into the cars by steam shovels, hauled to the embankment by dinkey engines, and dumped into place. After a train-load was dumped, the track was thrown over 10 to 12 feet. The earth was spread by road graders to a depth of 8 inches, sprinkled by road sprinklers, and then rolled with concrete rollers. The daily output of the shovels averaged about 630 cubic yards when conditions were favorable. During March, 1907, the output was 626 cubic yards per day; in April, 631 cubic yards; and in May, 636 cubic yards. In October, 1907, the average daily output was 865 cubic yards.

In the construction of the Tabeaud Dam,[1] mentioned under "Embankments," page 26, which is 100 feet high and contains 370,000 cubic yards of embankment, Mr. Burr Bassell gives the following costs per cubic yard: Plant charge, 1 cent; general expense, 2 cents; loading and hauling, 32.3 cents; spreading, 1.5 cents; sprinkling, 0.8 cent; harrowing, 0.6 cent; rolling, 0.8 cent; total, 39 cents.

The earth was moved by Fresno scrapers, wagons being loaded through "traps" (Pl. I, fig. 1). The dam was built by contract in 1901. During August, September, and October more than 2,000 cubic yards per day, or 53,000 cubic yards per month, were placed. The maximum force was 233 men and 416 horses and mules. There were 4 horses on each Fresno and each wagon. The structure

[1] See H. P. Gillette. Handbook of Cost Data. Chicago and New York, 1910, 2 ed., p. 791.

was built at a time when laborers could be had at $1.50 to $2 and horses at $1 per day. The wagons, tools, etc., exclusive of the horses, were worth about $16,000. Allowing 3 per cent per month for interest, depreciation, and repairs, the daily plant charge was about $20, or 1 cent per cubic yard. The general supervision and overhead charges, allowing 5 per cent for this item, were 2 cents more per cubic yard.

The average haul was one-fourth mile. The earth—a clay mixed with gravel—was spread in 6-inch layers, sprinkled, and rolled. Three road graders, each operated by 6 horses and 2 men, spread 2,000 cubic yards per day. There were 2 rollers, each operated by 6 horses and 1 driver, and 2 harrows, each operated by 4 horses and a driver.

The item of loading and hauling in this estimate is high on account of the method employed. By the use of modern elevating graders and dumping wagons, this cost should be much reduced when done on so large a scale.

DIMENSIONS OF EARTHEN DAMS.

The proper dimensions to adopt in the building of earthen dams can not be determined mathematically. The present knowledge of soil physics is too meager and the character of the materials differ too widely to admit of limiting the quantities used to the same extent as in the construction of a railroad bridge or a roof truss. The dimensions in each particular case must be left in a large measure to the good judgment and practical skill of the designer and builder. The character of the materials, the purpose for which water is stored, and the natural conditions surrounding each site differ so widely that it is impossible to lay down precise rules. Generally speaking, the dimensions will depend to a greater or lesser extent upon the following conditions: The danger to life and property in case of failure, the depth of water to be impounded, the height and force of the waves, the angle of repose of the materials, the pressure which they can safely withstand, the necessity of a roadway on top of the embankment, the slope paving, the imperviousness of the materials, the existence of a central core wall, and the manner of construction.

The top widths of the smaller dams vary from 6 to 20 feet. When teams are used to convey the materials, the smallest top width must be at least 6 feet. It is desirable often to have a roadway paved with rolled gravel and a fence around the reservoir, in which case a top width of 12 feet or more is required. Where stability and security alone are concerned, the top width depends to a large extent upon the elevation of high water.

In cold climates it is important that the high-water line be kept below the frost line in the upper part of the dam. Failures have been caused by the earth freezing in the trapezoidal section shown in figure

4, and elevating the section sufficiently to allow the water to pass along the division line. Failure may also be caused in weak embankments by the formation of ice at the flow line. If the force, due to the expansion of a layer of ice, be exerted against the frozen mass of earth in a weak embankment it may be sufficient to disturb the upper part of the embankment and endanger the whole structure.

There is the danger also of waves overtopping the embankment in both cold and warm climates. Few experiments have been made on the height of waves in small reservoirs, but safety requires that the surface of the water be kept at least 2 feet below the top of the embankment. In the smaller reservoirs the vertical distance between the water surface and the top of the embankment usually varies from 2 to 5 feet, whereas in the larger ones it is usually 5 to 10 feet.

In determining the size of an earthen dam it is perhaps best to fix the breadth at the flow line first. Converging lines may then be drawn through the extremities of this distance to suit the angle of repose of the material and other necessary conditions. The following table has been prepared from a study of more than 100 reservoirs in different parts of the United States, and is intended to serve as a rough guide in dimensioning the top portions of embankments.

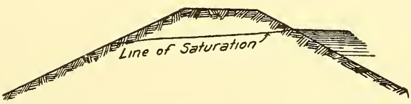

Fig. 4.—Line of saturation in an embankment, to be kept below the frost line.

Average dimensions of one hundred reservoirs.

Depth of water in reservoir.	Outer slope.	Inner slope.	Top width.	Height above water surface.	Breadth of dam at flow line.
Feet.			*Feet.*	*Feet.*	*Feet.*
10	2 to 1	2½ to 1	7	2	16
15	2 to 1	2½ to 1	8	3	21½
20	2 to 1	2½ to 1	11	3½	26¾
25	2 to 1	2½ to 1	14	4	32
30	2 to 1	2½ to 1	20	4	38
40	2 to 1	2½ to 1	25	5	47½
50	2 to 1	2¾ to 1	30	6	58½
60	2 to 1	3 to 1	35	7	70

Upon inspection of the above table it will be noted that the inner slope appears much flatter than the outer. This must necessarily be the case where an embankment is brought in contact with storage water, for if the inner slope be built steeper than 2½ to 1, the tendency of the wave action will be to reduce it to a flatter one and also to endanger the stability of the embankment.

It will be noted also that in each of the above averages the width of the embankment at the flow line exceeds the depth of the water in the reservoir by a distance varying from 6 feet in the smaller embankments to 10 feet in the larger ones.

CONCRETE AND MASONRY CORE WALLS.

Three kinds of core walls are common in the construction of earthen dams for the storage of irrigation water, namely; puddled walls, low-rim concrete walls, and high masonry walls. Puddled core walls are used as a general rule in the smaller and lower embankments. They have been discussed fully under a former heading.

In the larger embankments where a high masonry core wall is not considered necessary, additional security is obtained by building a low wall of concrete around the rim of the site. This wall extends from an impervious foundation to a few feet above the natural surface and serves the same purpose as a tongue and groove in lumber by preventing the passage of percolating water along the natural surface of the ground beneath the embankment.

The third kind embraces the standard type of masonry or concrete core wall which is built on a taper, with its broad base on bedrock or other safe foundation, and its narrow top rising above the flow line.

TRUE PURPOSE OF CORE WALLS.

There is a wide difference of opinion among hydraulic engineers as to the utility of the last-named type of core wall. Its advocates regard it as essential, and have given it too prominent a place in earthen dam construction. They have assumed, for example, in computing the stability of such structures, that the full hydrostatic head would be exerted against a core wall located in the center of the embankment. In adopting this view they ignore the upstream half of the embankment, which is the more impervious, and trust to the core wall and the material behind it. Nothing can be gained in thus magnifying the importance of the core wall at the expense of the embankment. The latter is the essential feature and should be so constructed as to resist successfully both the pressure of the reservoir head and the passage of percolating waters. A reservoir dam is in a precarious condition when the full head is exerted against a central core wall.

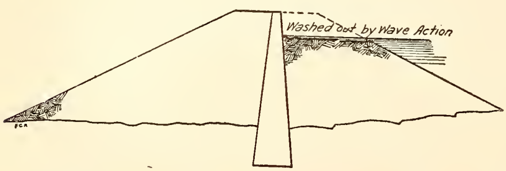

FIG. 5.—One of the many advantages of concrete core walls.

On the other hand, those who contend that masonry core walls are useless, go as far in the other direction Core walls may subserve a number of useful purposes. Chief of these are the stoppage of percolating waters beneath or at the sides of the dam, the prevention of the burrowing of animals, and protection against the action of waves. It is true that a low core wall will serve the first-named purpose, but

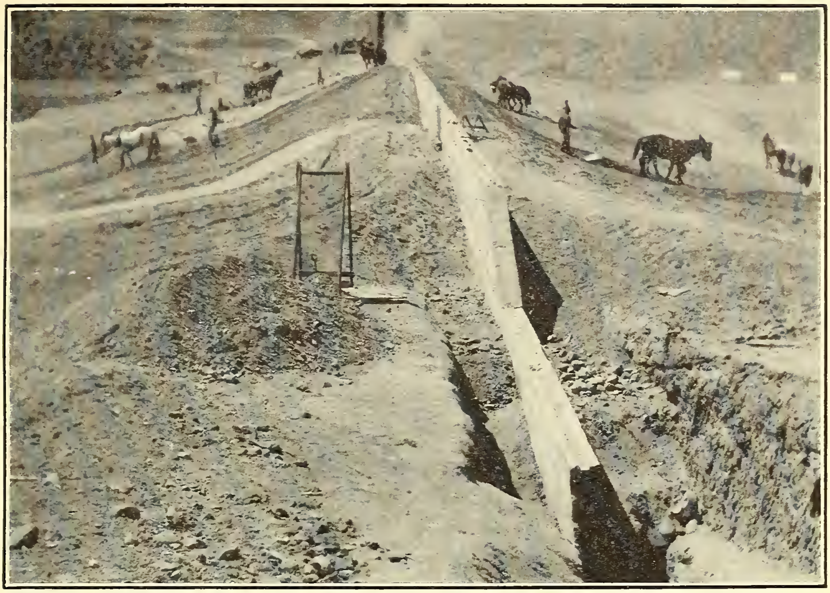

FIG. 1.—PLEASANT VALLEY IRRIGATION COMPANY'S DAM, SHOWING CONSTRUCTION OF COREWALL.

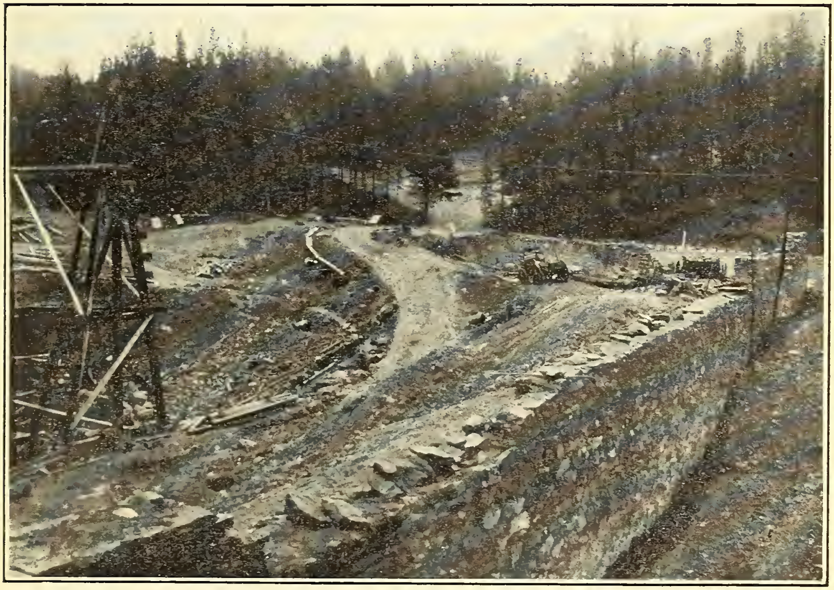

FIG. 2.—MASONRY COREWALL, MYSTIC LAKE DAM, MONTANA.

a high wall is needed for the other two. Figure 5 shows how a core wall may be the means of saving a dam partly eroded by wave action. In all districts infested with burrowing animals some kind of a rodent-proof wall may be regarded as a necessity. The present low price of cement would justify this extra expense were it only for this one purpose. The methods used in the construction of earth core walls have been fully discussed under the head of "Puddled core type," page 23.

TYPES OF CORE WALLS ILLUSTRATED.

PLEASANT VALLEY AND MAMMOTH DAMS.

Frequently the advantages of the puddled core and the concrete core types of dam are combined. The Pleasant Valley Irrigation Co. Dam in Selah Valley, near North Yakima, Wash., illustrates this feature. An excavation 12 feet wide extending to a cemented gravel bedrock and varying from 3 to 20 feet in depth was made with scrapers. The bedrock was roughened to insure a good bond between it and the concrete. The wall resting in the center of this trench was 3 feet at the base tapering to a thickness of 1 foot at a height of 13 feet, above which it was uniform in thickness to the present top of the dam, which is 43 feet above bedrock. The plans are drawn with the idea in view of a possible addition to the dam, raising it 25 feet, in which case the core wall will be tapered according to the plans, until it is 4 inches in thickness at the top of the addition. (Pl. II, fig. 1.) Selected earth was puddled on both sides of the concrete wall in the trench and continued through the embankment, thus making the total thickness of the concrete and puddled core 12 feet.

The contract price for the concrete of this core wall was $3.50 per cubic yard, the company furnishing cement, there being 1,401 cubic yards. The irrigation company also furnished all lumber and nails for the concrete forms, as well as the water. Washington-Portland cement was used, costing $3.15 at North Yakima and 35 cents per 100 pounds for freighting to the dam.

In the building of the Mammoth Dam, in Gooseberry Valley, Utah, a reinforced concrete core wall 2 feet in thickness was supported by buttresses of equal thickness on either side every 25 feet. These extended out 10 feet at the base from the center line of the core wall, and reached to within 20 feet of the top. The earth placed on either side of the concrete wall was well puddled. This dam has a maximum height of 100 feet.

MYSTIC LAKE DAM.

The Mystic Lake Dam south of Bozeman, Mont., on Bozeman Creek, illustrates a rubble masonry type of core wall. (Pl. II, fig. 2.)

It is 3 feet thick at the bottom and 2 feet thick at the top, extending 18 feet below the original water level of the lake. It rests upon bedrock upon the west side and upon clay for the balance of the distance. It reaches some distance above the level of the spillway. The embankment extends 35 feet above the original level of the lake. It is 360 feet long, 30 feet wide on the crest, and 200 feet wide at the base. It is constructed of an excellent quality of gravelly clay. The earth was puddled by running water upon it at night and allowing it to stand until morning, in a manner similar to that of the Ogden city reservoir, described on page 24. In the present instance the water

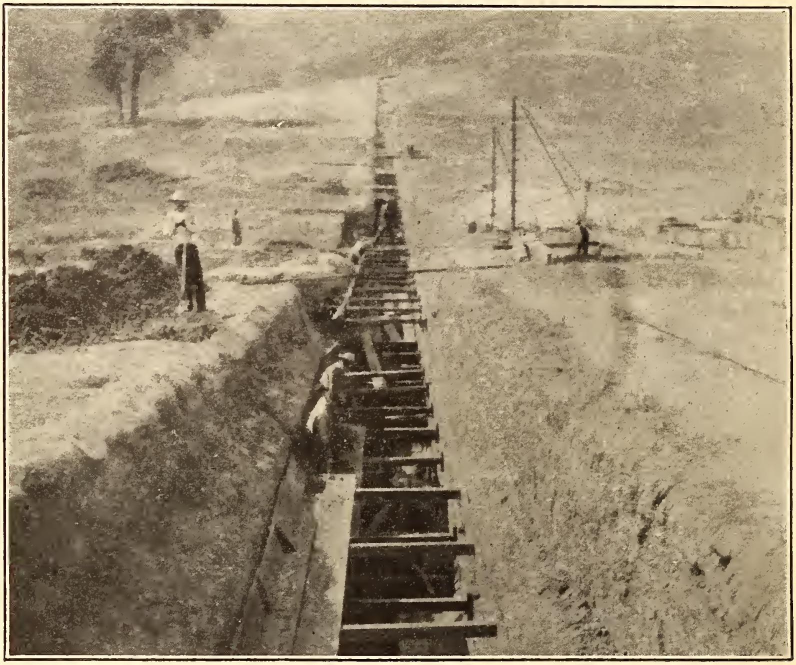

FIG. 6.—Shoring in trench for core wall and method of throwing up the earth, Silver Lake Dam, Los Angeles, Cal.

was brought out at night beyond the central trench, so that it covered a portion of each side of the embankment, the material being of a character that was quite easily drained. The contract prices for trenching for the masonry core wall and puddled earth were as follows: Earth, \$1; solid rock, \$2 per cubic yard.

Figure 6 shows a trench for a core wall in process of construction, giving the method of throwing up the earth, and illustrating how these trenches are carried well up on the hill sides.

ARROWHEAD DAM.

The Little Bear Valley Dam of the Arrowhead Reservoir & Power Co. of San Bernardino, Cal., is of the concrete core wall and hydraulic-fill

type. The procedure followed in building the embankment on either side of the core wall is taken up under "Hydraulic-fill dams," pages 74, 92. This dam is designed for a maximum height of 200 feet, a crest length of 880 feet, crest width of 20 feet, a 2½ to 1 slope on the upstream face, and a 2 to 1 slope on the downstream face. The core wall is 20 feet thick from its base, which rests upon a solid bed of blue granite, to the natural surface of the ground, a distance of 22 feet, and it is then battered on both sides to a thickness of 10 feet at a height of 63 feet, at which point it takes a batter that brings it to a thickness of 3 feet at the top, which is at the high-water line of the reservoir, the top of the embankment being 15 feet above that line. The core contains about 28,000 cubic yards of concrete. The contract price of the concrete work was $4 per cubic yard, the company

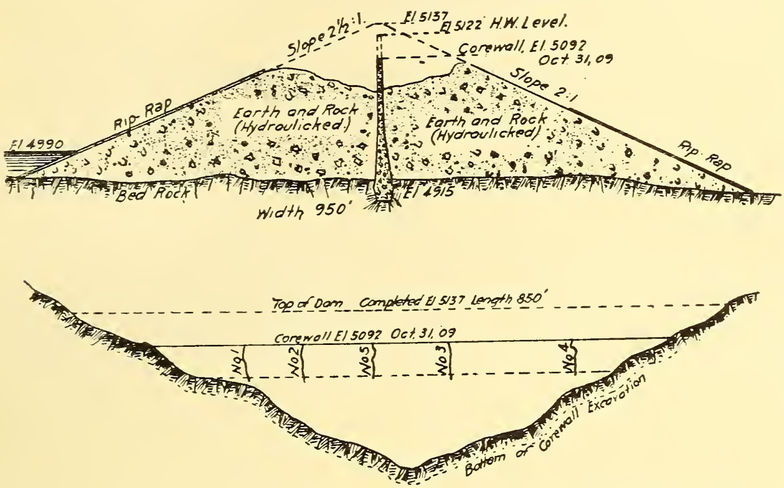

FIG. 7.—Cross section and location of cracks in Arrowhead Dam, Little Bear Valley, California. (Redrawn from Engineering News, Aug. 25, 1910.)

furnishing the cement. The rock was quarried about 800 feet from the end of the dam, a crusher being located near the latter. Material was carried over the top of the wall by a cable across the canyon. No rock was to be used, according to the specifications, larger than one-third of the thickness of the wall. California cement was used principally, costing about $2.50 per barrel in San Bernardino. The hauling for a distance of 24 miles over a road that crosses a high divide added $9 per ton to the cost of the cement.

The contractor in charge of this work was permitted to build some 30 feet of core wall ahead of the earth work in a locality where the elevation is 5,000 feet and where there is much freezing temperature.

On October 31, 1909, four fractures were noticed in the wall at an elevation of 155 feet above the stream bed, where the wall was 4.8 feet thick. On November 19, a fifth crack developed. Figure 7

shows the relative location of these cracks as well as a section of the dam and core wall, showing the stage of construction at the time the cracks occurred. The consulting engineer directed certain observations which showed there had been no movement of any consequence in the wall. Pits sunk at all the cracks showed that they ceased to exist at a depth of about 6 feet below the surface of the fill. The cracks varied in width from time to time, conforming strictly to changes in temperature. The wall was repaired by excavating down below the temperature cracks and adding a reenforced concrete curtain wall on the downstream slope, 18 inches in thickness, containing as much reenforcement as could be placed in this volume of material in order to strengthen the wall and make it as rigid as before the temperature cracks occurred. On the upper side of the wall buttresses 12 feet wide, 18 inches thick, and heavily reenforced, were constructed over the cracks.

INTERLOCKING STEEL SHEET PILING.

This form of piling has come to play quite an important part in modern construction of core walls and dams. Its use in a trench built for the concrete cut-off wall of the Silver Lake Dam, California, is considered under "Hydraulic-fill dams," pages 81, 82. Figure 38, page 82, shows the work of placing these piles in progress. In digging this trench quicksand was encountered and three rows of piling in 20-foot lengths were driven. Figure 8 illustrates one type of this piling, though there are many others on the market. The upper portion of the figure indicates the use of two lines of steel sheet piling, each 1,745 feet in length, which serve as a foundation for a concrete structure and also form core walls in the earthen embankments flanking each end of the central portion of the dam.

OUTLETS FOR RESERVOIRS.

ESSENTIAL FEATURES.

In designing outlets for reservoirs a few essential features deserve careful consideration. Among these may be mentioned capacity, safety, durability, and efficiency.

The first of the four factors named leads to a consideration of amount of discharge desired and size of outlet to carry it. Knowing the volume of water stored and the length of the period during which it will be used in irrigation, it is not difficult to compute the rate at which it should be discharged. It is more difficult, however, to determine the proper size for the outlet, since the discharge depends not only upon the size of the outlet but upon a varying head of water in the reservoir. While a small outlet may suffice for a full reservoir head it may be altogether too small for a reservoir nearly empty.

Nevertheless, to lessen the first cost it is desirable to decrease the size of the outlet as far as practicable and increase the velocity of water which passes through it. The minimum reservoir head which will produce the required discharge should therefore be as high as possible to gain this end. Water has been known to pass through the discharge pipe of reservoirs at a velocity of 100 feet per second. So high a rate of speed if long continued would prove destructive, but most outlets if properly built will successfully withstand a maximum velocity of 20 feet per second.

The second factor named, safety, necessitates the use of good material, properly placed. Especial care is needed in laying outlets through

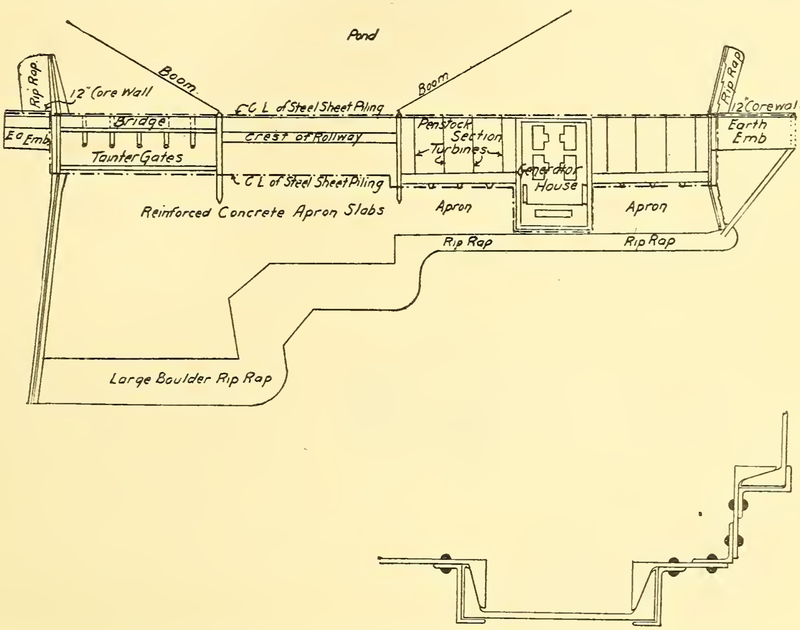

FIG. 8.—One of the many standard types of interlocking steel sheet piling, and its use in core wall of dam.

newly-made embankments on account of the tendency of the latter to settle. If possible, the outlet should be placed on a firm, unyielding base. A solid foundation usually can be secured by excavating below the natural surface, but if not, the right degree of solidity may be attained by the use of concrete. Great care must be taken also to prevent the passage of percolating water along the conduit. Where a masonry or concrete core wall is placed in a dam the outlet can be laid through the dam with greater safety in this respect, as the core wall will prevent water from percolating along the conduit. In the larger reservoirs, where conditions permit, an outlet is often made by tunneling through the natural bank at one end of the dam. This type is usually considered the safest and best. The danger of settling

and cracking is then minimized, especially when the tunnel is bored through solid rock. For illustration of this type, see the description of Lake Loveland Reservoir, page 46.

Durability is also a most important consideration in building an outlet. Formerly cast-iron pipes were largely used, but of late years concrete pipes and other forms of concrete conduits are replacing them to a large extent. The short life of lumber when in contact with earth and the expense and trouble of replacing it render this material unsuited for such purposes.

The efficiency of outlets depends in a large measure on all the other factors named, as well as upon simplicity in design; also, in a narrower sense, upon the ease and dispatch with which water can be drawn from the reservoir. There are many special contrivances in the way of gates, inlet chambers, and towers to regulate the time of withdrawal and the discharge required, a few of which, as well as of the outlet pipes and conduits, are described in the following paragraphs. The latter will be considered first.

CONCRETE PIPE FOR OUTLET CONDUITS.

The concrete pipe shown in figure 9 is made in straight sections with butting joints. Each joint is covered by a sleeve 8 to 12 inches long with a space of three-eighths to three-quarters inch between the pipe and the sleeve. For larger embankments and higher heads the reenforced concrete pipe illustrated in figure 10 is a good example. The intensity of reenforcing can be varied according to the pressures to be sustained. To assemble this pipe the sections are placed end to end and a strip of steel run through the hooks as shown. The open space over the hooks is then well grouted with rich cement thus forming a continuous pipe.

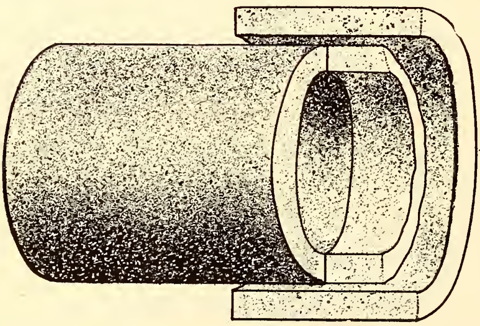

Fig. 9.—A standard type of concrete pipe.

In the manufacture of concrete pipe great care is required. Many failures have been recorded because of neglect to watch properly some detail of the process. Steel forms may be purchased at small expense, by the use of which short sections with either butting or bell-shaped joints are made. These forms may be had for all the more common sizes of pipe.

The first caution is to use fresh, dry cement of good quality and coarse sand or gravel free from all clay or dirt. The gravel is usually

taken from the river beds and screened to a size not greater than one-half the thickness of the pipe. The proportion of cement to be used in the mixture will be determined by conditions in every case. In general it may be said that a richer mixture should be used than is required for ordinary concrete work to insure imperviousness. In the manufacture of the smaller sizes, mixtures run from 1 part cement to 3 and occasionally 4 parts coarse sand. In larger pipes, having thicker shells, gravel may be introduced and the mixtures may then vary from 1 part cement to 4 or 5 parts sand and gravel combined. Where the shell reaches 5 or 6 inches in thickness, the mixture may be reduced to about 1 part cement to 6 parts sand and gravel combined. Sufficient water should be used in mixing to allow perfect crystalization of the cement. There is an advantage in having the mixture sufficiently dry to permit of removal of forms immediately after the pipe is cast, yet the wetter mixtures produce a stronger and more impervious concrete. They should be made just wet enough to pack and not spring. After thorough mixing, the material is fed into the forms in small quantities and tamped until the water rises to the surface each time.

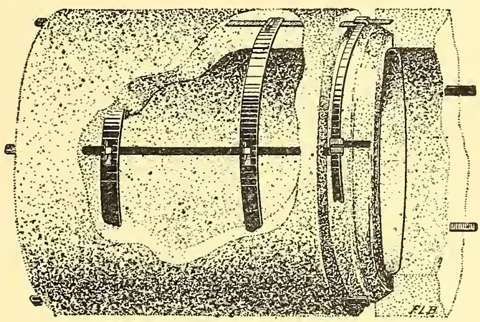

FIG. 10.—A common type of reenforced concrete pipe.

One of the most fruitful sources of trouble in concrete-pipe manufacture is failure to give due attention to proper curing. The strength of the pipe depends much on the care given to this feature. After removing the forms the section should stand in a cool, shaded place, not exposed to wind currents, and kept wet for at least one week, and preferably two weeks, by frequent sprinkling, covering with wet sacks, or by immersion under water. The work should not be undertaken in frosty weather.

It is a good plan before laying pipe to wash the inside of each section with neat cement. This decreases porosity and consequent sweating and gives a surface more free from friction.

In the construction of the first 2 miles or more of the pipe line of the Pueblo Water & Power Co.,[1] supplying the city of Pueblo, Colo., concrete pipe 30 and 38 inches in diameter was used. This pipe was made in 2-foot sections with hub and spigot joints, the shell of the 38-inch size being 3¼ inches and that of the 30-inch size 2½ inches thick. The sections intended for use in the deeper trenches were reenforced by seven rings of No. 5 annealed wire, while the others were made

[1] Engin. Rec., 57 (1908), No. 14, pp. 400, 401.

plain. The concrete was made in the proportions of 1 part Portland cement to 4½ or 5 parts gravel obtained from the river, the proportion depending upon the percentage of voids in the gravel. The latter was of excellent character for the purpose, varying from sand to stone that would pass a ¾-inch screen. The concrete was mixed by hand and thoroughly hand-tamped in the molds. Samples of this pipe were tested when 15 to 26 days old. The tests demonstrated that pipe reenforced with the annealed round wire could be safely used in trenches over 12 feet deep, while the plain pipe had ample strength for the balance of the work. The mixture for the concrete was made dry enough so that water would flush to the surface only under thorough tamping. The dry mixture of concrete was used in order that the molds could be removed immediately after the pipe was cast. Gangs of three molders each cast sixteen 2-foot sections of 38-inch pipe or twenty 2-foot sections of 30-inch pipe in a 10-hour day.

In the Rock Creek Conservation Co.'s project at Rock River, Wyo., about 288 feet of concrete bell pipe was made to conduct the canal water down a hillside. This pipe was 36 inches in diameter, with a 3-inch shell. The mixture used was 1:2:3, and was reenforced with ordinary barb wire, six rings being used to each pipe. The concrete was mixed by hand and placed very wet and allowed to stay over night in the forms which were painted with crude oil before every setting.

The cost of the pipe making and laying was as follows:

Cost of making and laying pipe.

Labor and teaming:		
Mixing and placing in forms (810 hours)	$202.50	
Hauling water	25.00	
Oiling and setting forms, and foreman	47.40	
		$274.90
Materials:		
Cement (220 sacks, at $2.20 per barrel)	121.00	
Sand (33 cubic yards, at $4.80 per yard)	158.40	
Oil	10.00	
Barbed wire	10.50	
		299.90
Total		574.80

This was $2 per linear foot. The laying cost $86.50, or 30 cents per foot. The excavation and backfilling of the trench by slip scrapers cost $176.10, or 61 cents per foot. The total cost of manufacture, laying, and trench work therefore was $2.91 per linear foot.

Gravel for the above work was obtained from the creek and was screened and hauled at a contract price of $6.70 per cubic yard. Sand was shipped from Laramie, costing 40 cents per ton, the freight being $1, and hauling to the site $1.80 per ton. A local Colorado

brand of Portland cement was used costing $2.20 per barrel laid down at Rock River, and was hauled to the site by company teams.[1]

The laying of the pipe also should be attended with great care. After being assembled on a good foundation and the sleeves properly adjusted, the space between joint and sleeve is filled on all sides with a somewhat richer mixture than that used for the pipe, so as to form a water-tight joint.

OUTLET CONDUITS AND GATES FOR SMALL RESERVOIRS.

The best location for the outlet gate, if there be but one, is at or near the intake end of conduits. In that case, if there is any leak in the conduit the water can be shut off while repairs are being made. This necessitates the erection of an operating tower or platform over the inlet end and a bridge to reach the same, but the additional expense, if any, is slight, and is a means of insurance against leakage and breaks.

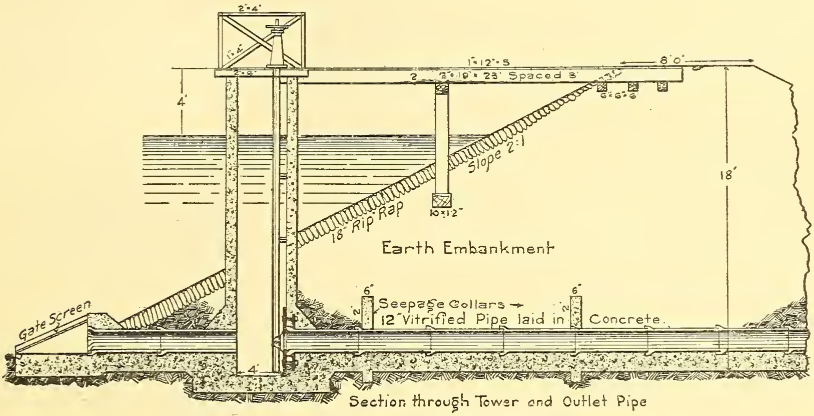

FIG. 11.—An adaptation of vitrified pipe for small reservoir outlets.

A cheap and practical type of outlet to conduct water from a small reservoir is obtained by the use of vitrified sewer pipe or cement pipe built in sections. Figure 11 shows an adaptation of the former pipe. In laying this pipe it is important that the foundations be firm, as a slight settling may cause an opening of the joints or a crushing of the pipe. The upstream entrance to the pipe is protected by a gate screen built either of small iron rods crossed one on another or a heavy wire screen with a coarse mesh. The water then flows to the gate tower where the discharge is controlled by a cast-steel slide gate. Figure 12 shows an elevation and section of this gate, which may be procured in all the regular sizes from 3 to 36 inches. This gate is fastened to the pipe by means of a collar placed back of the flange

[1] Engin. and Contract., 36 (1911), No. 26, p. 690.

on the pipe and bolted securely to the face piece upon which the gate slides. The same figure shows the lifting device by means of which the gate is raised and lowered. Earth can be puddled about vitrified pipe so that very little seepage water will find its way along the outer surface, but as a further precaution it is good practice to place one or two concrete seepage collars around the upstream third of the pipe.

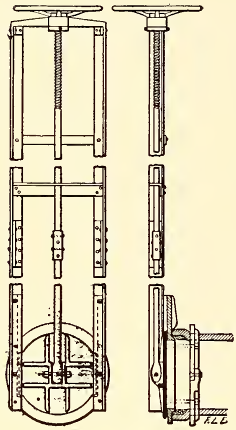

FIG. 12.—Outlet gate for small embankment, showing connection for vitrified pipe.

Another type of gate suitable for use in small reservoirs which may be readily adjusted to vitrified, cast-iron, or concrete conduits is the one installed at the Escondido Dam, California. Figure 13 gives a front elevation and section. The gate is of cast-iron with brass facings, set in a frame also faced with brass and bolted to the cast-iron outlet. It is set at the incline of the upper slope and is controlled, through the medium of a long rod, by means of a worm gear mounted as shown. The figure as shown gives a clear idea of the method of adapting the gate to concrete-lined reservoirs.[1]

An outlet tower which is operated successfully on a Montana farm is shown in figure 14. The depth of water in the reservoir is about 7 feet. The construction of the tower is self-explanatory from the sketch. The two partitions of the flashboards are inserted to secure water-tightness. The height of the water in the reservoir and the outflow are regulated by taking out or replacing the flashboards. The water is supplied from a spring. When the reserve supply conserved by the reservoir is entirely withdrawn during the day, the flashboards are set so that when the water has reached the limiting height the surplus flows over the flashboards and out through the pipe into a ditch.

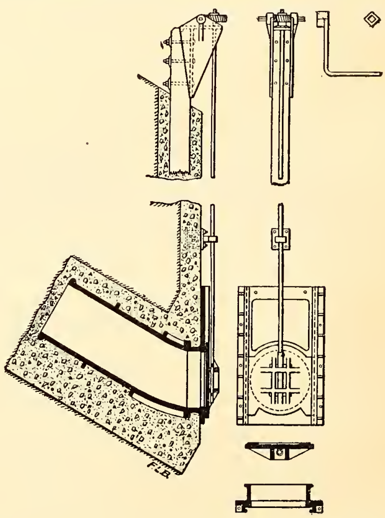

FIG. 13.—Outlet gate, Escondido Dam, Cal., adapted to concrete-lined reservoirs. (Redrawn, with modifications, from Schuyler's "Reservoirs for Irrigation," etc., p. 11.)

An inlet valve which is very effective where there is likely to be a deposit of material in the reservoir is shown in figure 15. This valve was designed by H. N.

[1] Redrawn from J. D. Schuyler. Reservoirs for Irrigation, Water-power and Domestic Water-supply. New York and London, 1908, 2. ed., p. 11.

Savage, now in the United States Reclamation Service, and was installed in the early nineties in connection with the Sweetwater Dam in southern California. The outlet pipe is fitted at its discharge end with a standard gate valve and at the reservoir end with the valve as shown. When the lower gate valve is open, the pressure of the water from the reservoir on the upper valve is usually too great to permit it being lifted from its seat. By closing the gate valve and tightening the valve spindle or chain, the small

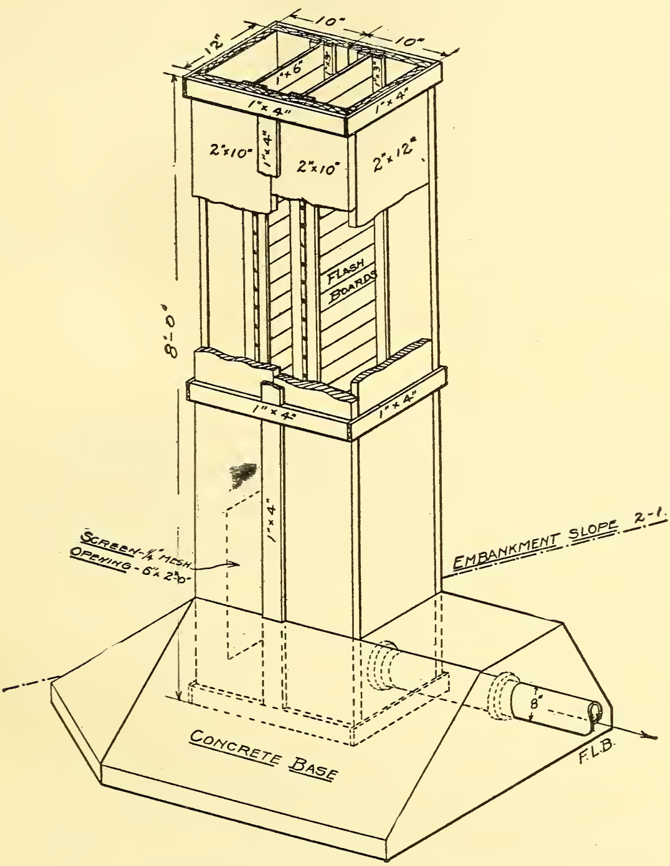

FIG. 14.—An outlet tower used on a Montana farm.

auxiliary valve shown in the drawing is easily lifted owing to its small size. The intervening pipe between the gate valve and the valve shown is then filled through the auxiliary valve. When the pipe is full the larger valve can be lifted. The gate valve is then operated to regulate the discharge. By means of this valve the inlet elbow is kept free from the deposit of silt which might otherwise choke the outlet pipe and cause considerable trouble and delay.

Another arrangement of valves for cast-iron pipe is shown in figure 16. The object of the two gate valves is to have a provision for safety. In case one becomes impaired the other will still retain the water.

OUTLET CONDUITS AND GATES FOR LARGE RESERVOIRS.

Attention has been directed to the advisability of building outlet conduits for the larger reservoirs through the natural bank at one end of the dam. Failure caused by settling of the embankment upon the conduit is illustrated in the break which occurred in the Empire Reservoir dam near Orchard, Morgan County, Colo., early in August, 1909, as described by the State engineer.[1]

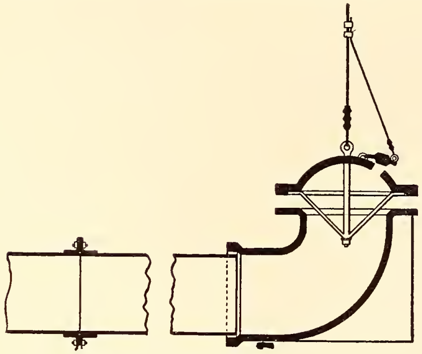

FIG. 15.—Valve of Sweet Water Dam, Cal. (Designed by H. N. Savage, U. S. Reclamation Service.)

This break was evidently caused by a leak in the conduit which had cracked from settling. The water jetting through these cracks washed the earth fill from around the conduits and from underneath the gate well, which was in the center of the dike. The gate well soon collapsed, breaking the conduits and destroying the gates, the unchecked flow rapidly washing away the outer and central portions of the dam. This failure illustrates the mistake of locating gates in wells in the center of the embankment. If the gates had been located at the inlet end of the conduit they could have been operated independently of the collapse of the conduit, while necessary repairs could have been made in the latter, and the disaster averted.

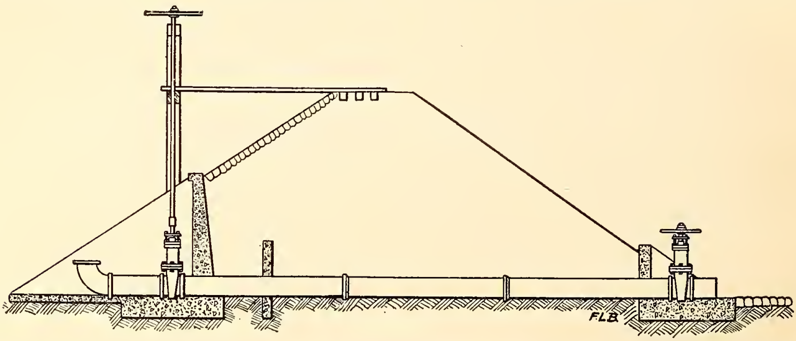

FIG. 16.—Cast-iron outlet with secondary gate.

[1] Bien. Rpt. State Engin. Colo., 15 (1909–10), pp. 93, 94.

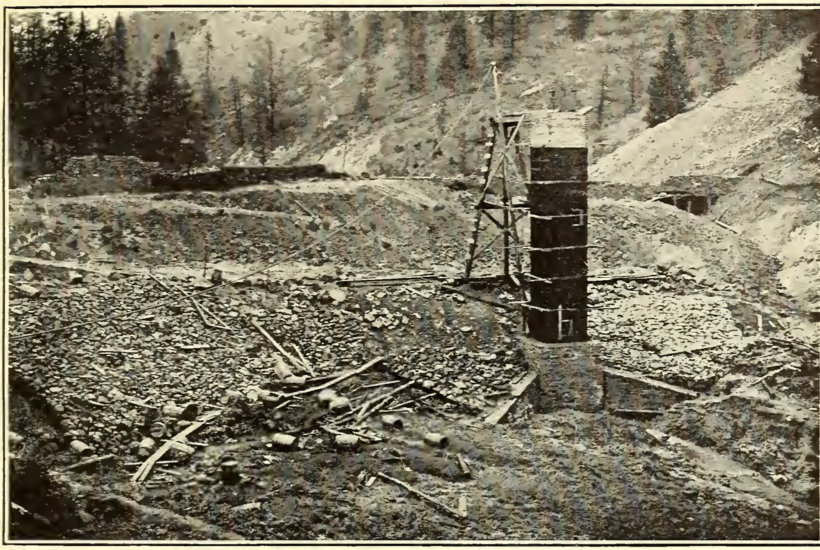

FIG. 1.—OUTLET TOWER AND EMBANKMENT OF MYSTIC LAKE DAM, MONTANA, UNDER CONSTRUCTION.

FIG. 2.—PLACING STANDARD GATES, LEWISTON-SWEETWATER PROJECT, IDAHO.

Tunnels are sometimes built which contain two or more pipe conduits. The advantages of this arrangement is that the pressure on the pipes due to weight of embankment above is removed and repairs are facilitated. One line is kept in constant use while repairs are being made upon the other. Where for reasons of economy or otherwise the building of a tunnel for the above purpose is considered impracticable, the pipe lines may be laid in a bed of concrete which extends about half way up the sides of the pipe, the upper portion of the pipe being protected by a layer of concrete 3 or 4 inches thick. This takes the strain from the weight of the embankment off the pipe and prevents its cracking as the embankment settles. This type of outlet is illustrated in figure 17. The Douglas Reservoir on Dry Creek, 10 miles northeast of Fort Collins, Colo., has this type of outlet.

A combination of vitrified and cast-iron pipe is occasionally used for an outlet, the gate valves being set between two lengths of the latter. The Oasis Reservoir on Barr Lake, Adams County, Colo., has this type, there being a double line of 24-inch pipe well protected by the usual concrete collars, and inlet and outlet cut-off walls. Plate III, figure 2, illustrates the placing of standard gates on the Lewiston-Sweetwater Irrigation Co.'s project near Lewiston, Idaho.

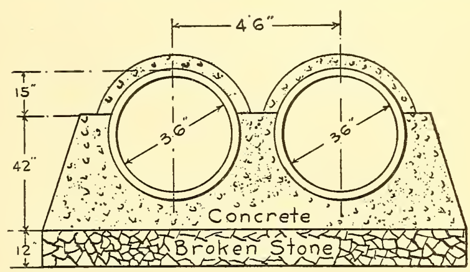

Fig. 17.—Section showing pipe conduits supported on concrete base and protected by concrete arches.

The following descriptions of outlets further illustrate construction used on some of the larger projects:

An outlet tower of inexpensive type is shown in course of construction in Plate III, figure 1. The rubble masonry core wall of the dam, also in course of construction, may be seen in the distance in the same figure. The tower has a masonry base with wing walls extending in either direction and a square wooden top. Two lines of cast-iron pipe, one 16 inches and the other 12 inches in diameter, convey the water from the tower beneath the embankment, each pipe being controlled by a gate located within the tower. Rectangular openings controlled by sluice gates admit water into the upper division of the tower at different elevations. The wooden portion of the tower was built of 2 by 6 inch planks, spiked flatwise, one upon the other, as shown in the figure. A course of 2-inch planking was nailed upon the outside of this framework, making a wall of 8-inch thickness. A bridge connects the tower with the top of the dam.

The outlet for Lake Loveland,[1] a reservoir near Loveland, Larimer County, Colo., instead of being made through or below the dam was made through the natural bank at one end of the dam. The structure was built in 1896 before the use of concrete in irrigation structures became general. The conduit is a pipe of hard brick laid in cement. It has an inside diameter of 5 feet and is 3,400 feet long.

The upper end of the outlet conduit extends into a tower of hard brick in which the gates are operated. The tower is 150 feet out from the water's edge when the reservoir is full, making it necessary for the operator to use a boat to reach it. The tower is built on a concrete foundation 3 feet thick. The remaining part of the tower is brick and is 51 feet high. The first 15 feet of the tower is 7 feet square (inside) with 3-foot walls. Above this the inside is circular, the inside diameter being 8 feet, with walls tapering from 3 feet at the bottom to 16 inches at the top. A wooden floor is placed around the outside, at a height of 42 feet above the base, and at the same level inside. The outlet gates are operated from this floor. The outlet pipe is enlarged at its opening into the wall and tapers for a distance of 16 feet until it becomes 5 feet in diameter. The water enters the tower through two openings, one of which is at the bottom on the north side and the other is 3 feet above the base on the west side, each opening being $2\frac{1}{2}$ feet wide and 3 feet high. The openings are covered by both inside and outside gates. The gates are 1-inch cast iron, having wrought-iron ribs bolted to the back of them. The cost of the outlet works and long tunnels was $125,000.

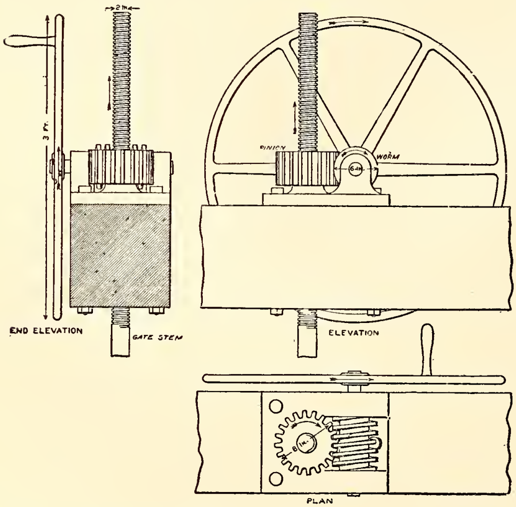

FIG. 18.—Design of lifting apparatus used at Lake Loveland and Mariano reservoirs.

A very powerful apparatus for lifting an outlet gate is shown in figure 18. This is the type used on the Lake Loveland project. The threaded gate stem first passes through a pinion 8 inches in diameter, which acts as a nut rotating horizontally, but having no vertical motion. The pinion gears with an endless screw or worm 6 inches

[1] U. S. Dept. Agr., Office Expt. Stas. Bul. 134, p. 56.

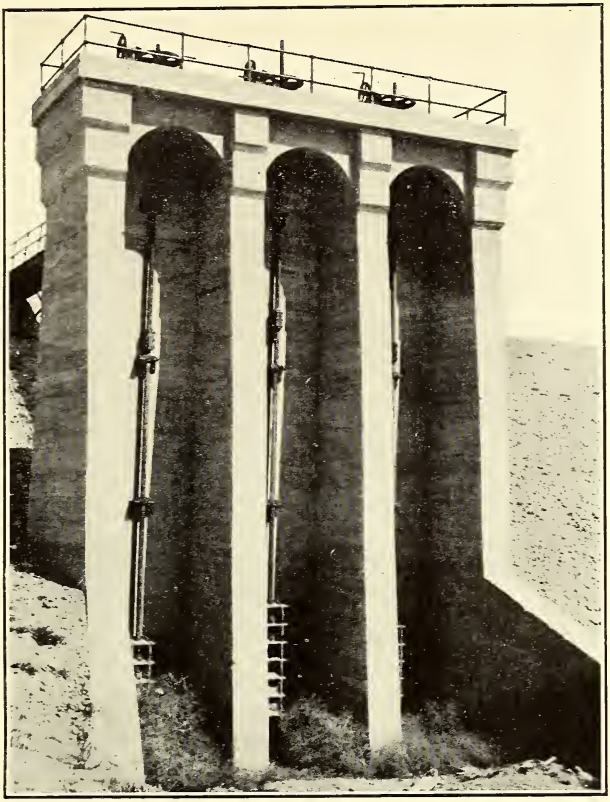

FIG. 1.—GATE TOWER AND GATES, LOWER EMBANKMENT, BOISE PROJECT, IDAHO.

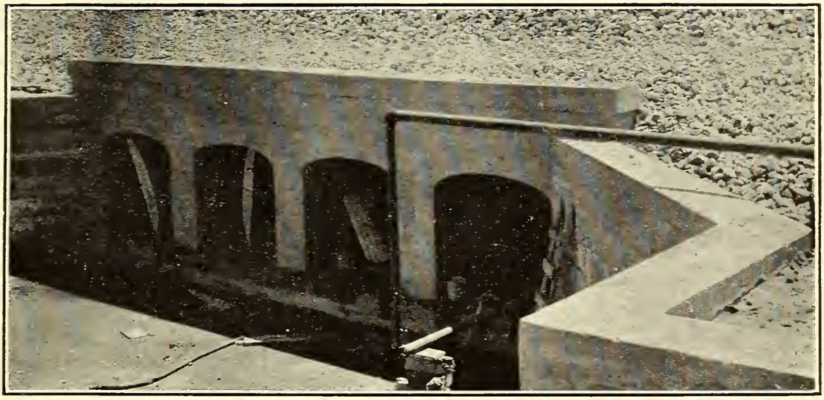

FIG. 2.—OUTLET OF CONDUITS, EAST END UPPER EMBANKMENT, BOISE PROJECT.

in diameter placed on a horizontal shaft to which is attached a hand-wheel 3 feet in diameter.

The Deer Flat Reservoir of the Boise project (Idaho), United States Reclamation Service, has two outlets, one at the Upepr and one at the Lower Embankment.

The general plan of these outlets is the same, each consisting of a reenforced concrete conduit and inlet tower. The inlet tower at the Lower Embankment is shown in Plate IV, figure 1. The inlet gates to the Upper Embankment, with tower under construction, are shown in figure 19. The outlet of the conduit is shown in Plate IV, figure 2. A plan, section, and elevation of the upper outlet is shown in figure

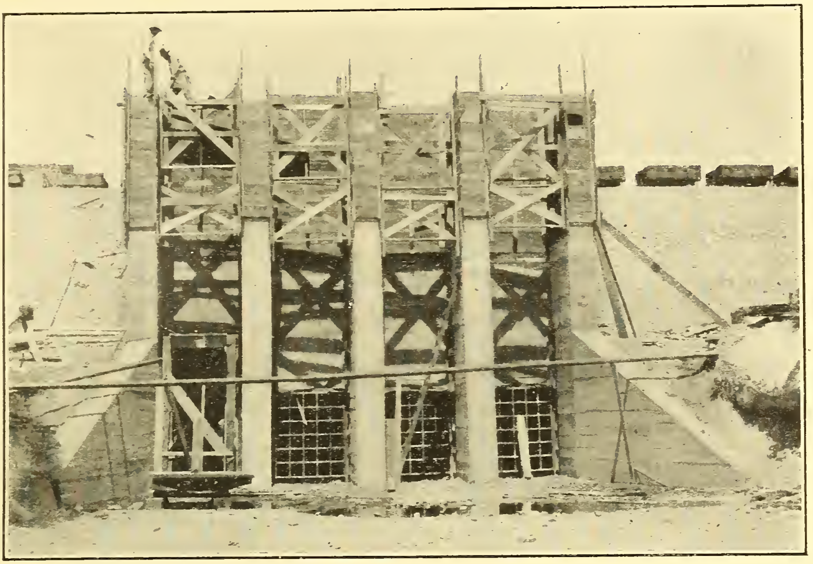

FIG. 19.—Tower under construction and entrance to conduits, east end outlet, Upper Embankment, Deer Flat Reservoir, U. S. Reclamation Service, Idaho.

20. In order to support the great weight of embankment above it, half-inch reenforcing bars spaced 12 inches center to center are placed transversely in the top of the conduit in such a manner as to prevent the spreading and the consequent crushing of the opening. The conduit extends through the base of the dam and is founded on a solid gravel bed. It has a total length of about 210 feet, with an outside width of 33 feet and an outside height or depth of 9 feet. It is divided into four circular channels, each having a diameter of 6 feet, with intercepting walls 2 feet thick at the smallest section. The thinnest section at the top of each channel is 12 inches and at the bottom it is 2 feet. Seepage water is prevented from finding its way along the conduit by collars 19 feet high, 43 feet wide, and 18

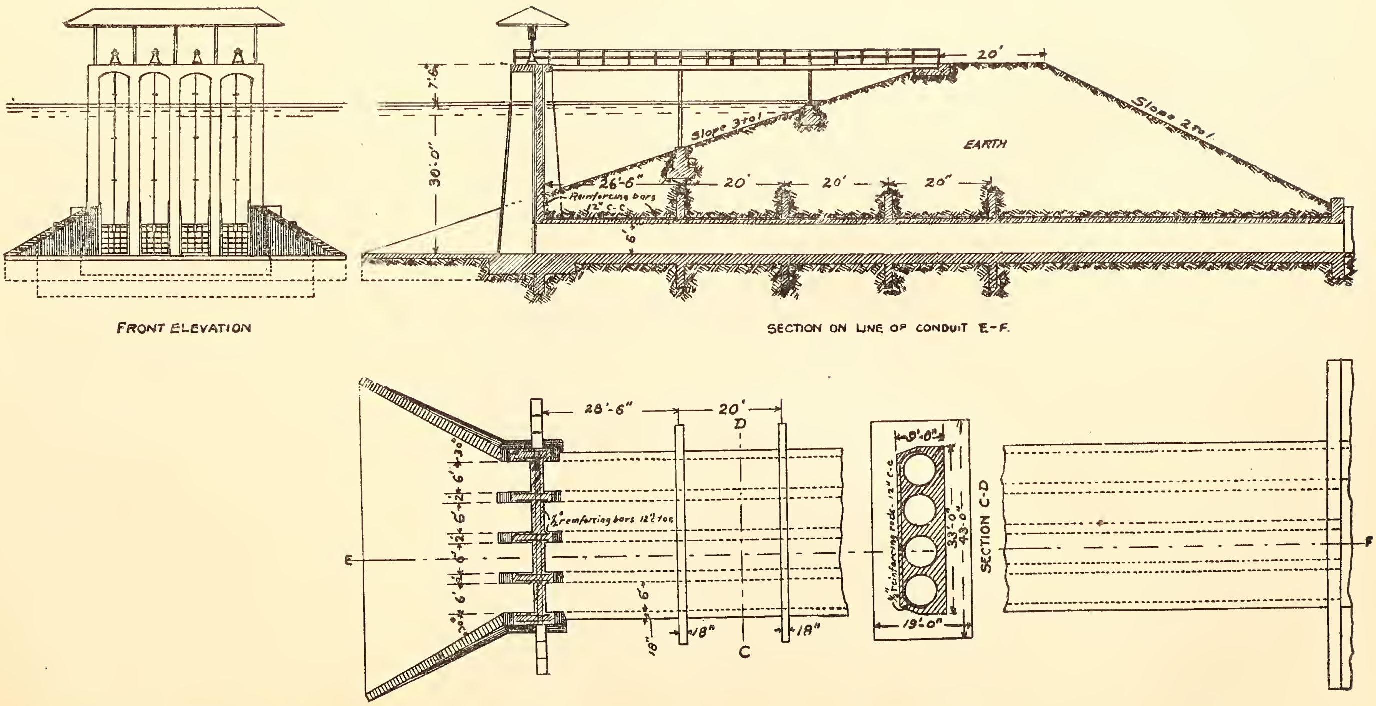

FIG. 20.—Elevation, section, and plan, east end outlet, Upper Embankment, Boise project, Idaho. (Plate XL, Fifth An. Rpt. U. S. Reclamation Service.)

inches thick in the upper portion of the conduit, spaced 20 feet center to center. The first collar is 26 feet 6 inches from the inlet opening. These collars extend 5 feet out all around the conduit.

The flow of water through the 6-foot channels is controlled by standard sluice gates, which are operated by geared lifting devices of the type most used by the Reclamation Service.

The floor of the tower upon which these devices rest is 37½ feet above the floor of the outlet channels. The tower consists of five parallel buttressed walls joined by a central wall of four panels, in which are located the openings into the several outlet conduits. The three inner walls are spaced 8 feet center to center and the outside walls 8¼ feet from the centers of the inner walls, respectively. The crest of the tower is 8 feet wide and 35 feet long. The buttress walls are vertical from the crest of the tower downward to the high-water line, 7½ feet, below which they have a batter, front and back, of 1 in 12, to the level of the floor channels. The foundation of the tower is of solid concrete 4 feet thick with a cut-off wall extending 4 feet below the foundation and out on both ends. The floor extends about 35 feet beyond the outlet gates. The side edges of the floor are limited by wing walls which have slopes coinciding with the slope of the embankment. A bridge extends from the crest of the dam to the top of the tower.

The outlet conduit of the Hatchtown Dam, Utah, also extends through the base of the dam. The trench for the tunnel was about 320 feet long and was cut down to hardpan at a point in the dam where the tunnel would command the largest available supply. The trench was 13 feet wide and 18 feet deep. The tunnel is arched at the top, the inside measurements being 5 feet wide and 8 feet high, with walls 4 feet thick built of rubble masonry. It is enlarged at the gate well to receive two gates which operate side by side. The gate well is built of reenforced concrete and is located in the upstream slope of the dam in front of the puddle core. All the rods in the reenforcing are one-half inch square, soft steel, and spaced 15 inches apart.

The flow of water is controlled by two large steel gates 4 feet 8 inches wide, 5 feet 2 inches high, and 1¼ inches thick, which are raised and lowered by a standard type of lifting mechanism.

The outlet conduit of the Mammoth Reservoir in Utah consists of a 5-foot reenforced, concrete, arched tunnel, located in the old stream bed. The dam is of the concrete core-wall type. The tunnel is ribbed on the outside with concrete collars at intervals of about 15 feet. (Pl. V, fig. 2.) Before filling in the embankment the earth was puddled around the tunnel for a depth of several feet, making as compact a seal as possible between the earth and concrete. The outlet tower contains two slide gates similar to those shown in

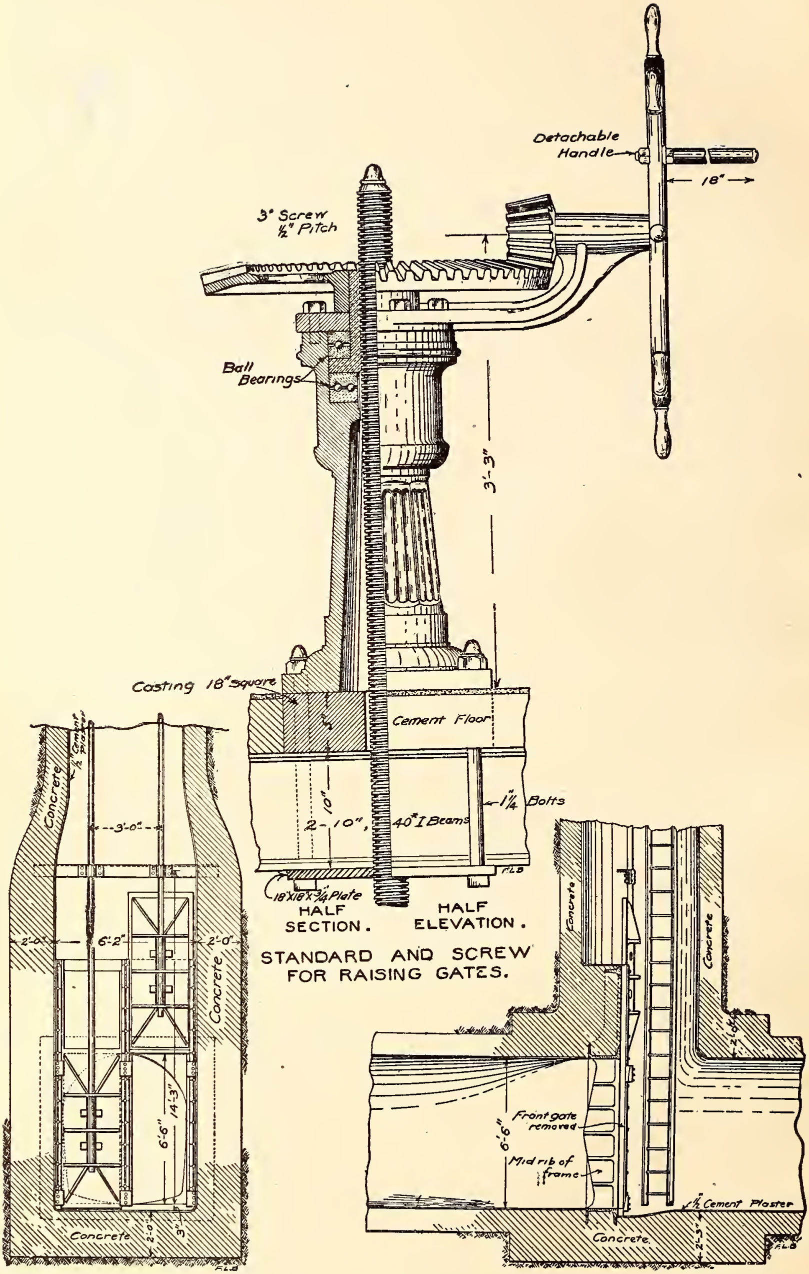

FIG. 21.—Section of gate tower, and lifting device, Mammoth Dam, Utah.

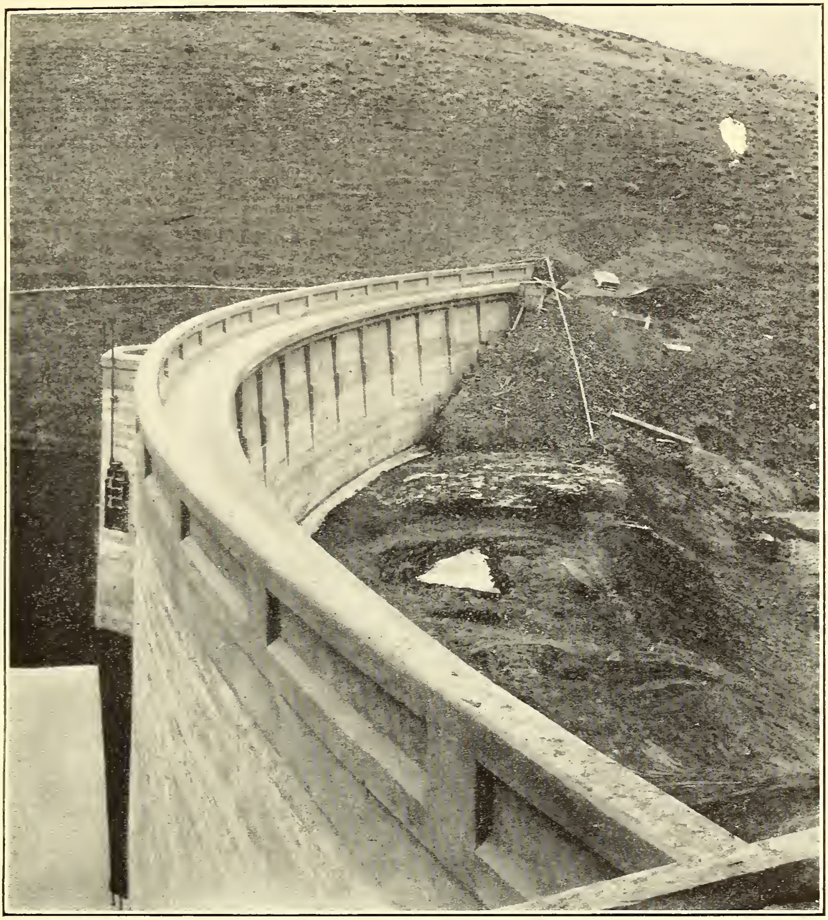

FIG. 1.—LEWISTON-CLARKSTON DAM, CLARKSTON, WASH., SHOWING POSITION OF OUTLET CHAMBER AND GATES.

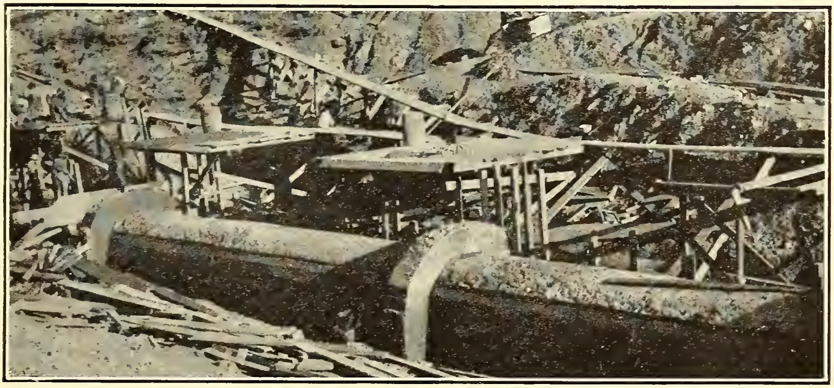

FIG. 2.—OUTLET TUNNEL, SHOWING SEEPAGE COLLARS, MAMMOTH RESERVOIR, UTAH.

figure 21. These gates are raised with a rack-and-pinion lifting device, the pinion being threaded to the stem of the gate rod, as shown n the same figure.

In the larger concrete dams the outlet gates are frequently operated from a valve tower or chamber attached to the center of the main structure on its upstream face, as shown in Plate V, figure 1.

SLOPE PROTECTION.

THE OUTER SLOPE.

The main purpose of protecting the outer slope of reservoir embankments is to minimize the cutting away of earth by pelting rains. This effect is plainly seen in Plate VI, figure 1, which illustrates a part of the outer slope of a dam belonging the Whittier Land & Water Co. of California. This slope was built too steep and became much eroded by the action of storm water alone. An inexpensive protection against both rain and wind consists in covering such slopes with rich loam and seeding to suitable grasses. The sod when once formed will prevent the erosive action of rain, and the storm water can be readily removed in small, paved ditches. Where grass can not be made to grow or is unsuitable, a layer of broken rock or coarse gravel and cobbles is often substituted. This affords not only protection against wind and rain but does much to keep out gophers and other burrowing animals.

THE INNER SLOPE.

In the case of the upper or water slope the problems are of a different nature. A reservoir located in the open, subject to the sweep of the wind, and having a long reach of water is certain to develop high waves, which will spend a most destructive force upon an unprotected embankment. Figures 22 and 23 show such waves in action and the results. Unless an earthen dam is well protected against forces of this kind, overtopping and ultimate failure may be expected. Some of the more common methods of protecting these reservoir embankments in the irrigated districts are herein described.

TEMPORARY BRUSH PROTECTION.

In Colorado many farmers have secured temporary protection to their reservoir slopes by using straw and barbed wire. Posts are driven at intervals of 2 to 4 feet at a point 2 or 3 feet below the flow line or high-water mark of the reservoir. These posts project about 3 feet above the water surface. Strands of barbed wire 4 to 6 inches apart are stretched on the upper side of these posts extending below the water line to the earth slope. Straw is then placed in a regular thatch back of the posts and up the embankment slope, and packed in

firmly to the level of the tops of the posts. The straw is weighted down by large cobbles, sloping from the posts to the crest of the embankment. This revetment of straw and cobbles protects only a small portion of the slope area. However, as the amount of water is drawn down in a small reservoir the inclosing embankments form windbreaks, and the wave action is largely reduced. The straw revetment therefore serves as a protection at a point where the waves are the largest and most destructive.

Where brush and willows are plentiful it is not uncommon to thatch the water slope with bundles of willows. The better class has its bundles bound by galvanized-steel wire (Pl. VI, fig. 2). More generally, however, heavier brush is used and anchored with stone or slag. Occasionally the rock or slag is dumped into the water from the top of the inner slope and allowed to roll into position.[1]

FIG. 22.—Effects of wave action upon an embankment of a Colorado reservoir.

During the construction of the Silver Lake Dam, Los Angeles, Cal., a temporary brush riprap was placed upon the water slope as shown in Plate VI, figure 2. Long, slender pieces of brush 1 inch to 2½ inches in diameter were tied at the butts with baling wire into bundles 1 foot in diameter. The brush end was thrust into the water with the butts extending up the slope. The brush was 8 feet long, and about 5 feet down from the butts stakes 2 to 2½ inches in diameter were driven 2 to 3 feet apart, holding the brush in place. This protection proved very satisfactory, and when the dam was completed the slope was covered with a concrete paving.

HAND-PLACED RIPRAP.

The earth should first be covered with a layer of gravel or of small broken stones, so as to prevent washing through the joints of the paving.

In the building of the Sevier Bridge Dam near Juab, Utah, the water slope was paved with rock 18 inches thick, carefully placed with the interstices thoroughly filled and rammed with gravel. This rock fac-

[1] Utah Sta. Bul. 46, p. 37.

FIG. 1.—EROSION OF RESERVOIR SLOPES BY STORM WATER ONLY, WHITTIER LAND & WATER CO., CAL.

FIG. 2.—TEMPORARY SLOPE PROTECTION. BUNDLES OF WILLOWS TIED WITH GALVANIZED WIRE AND ANCHORED BY STAKES, SILVER LAKE DAM, CAL.

FIG. 1.—HAND-PLACED RIPRAP, MILLER & HARMON RESERVOIR NO. 1.

FIG. 2.—HAND-PLACED RIPRAP, MAMMOTH DAM, SANPETE COUNTY, UTAH.

FIG. 3.—CYCLOPEAN RIPRAP, MINIDOKA DAM, IDAHO (U. S RECLAMATION SERVICE).

ing extends from the top of the dam down to hard material at the bottom of the slope. At the top of the slope the riprap extends onto the crest of the dam for a distance of 4 feet. The company maintains a fence along both edges of the crest to protect the riprap from stock.

The Miller & Harmon Reservoir Dam No. 1, one mile northeast of Louisville, Colo., is another illustration of hand-placed paving. Owing to the high winds in the vicinity of the dam there is considerable wave action. The paving is a heavy riprap of loose stones extending to a depth of 18 inches. These were laid with care and a structure of very permanent character was obtained. (Pl. VII, fig. 1.) Plate VII, figures 2 and 3, are also good illustrations of hand-placed riprap, the latter being on one of the United States Reclamation Service projects.

The upstream slope of the Mammoth Dam, Gooseberry Valley, Utah, is protected with a carefully hand-laid riprap 18 inches deep, thoroughly grouted with cement. The slope was well tamped before laying the riprap, making a firmer foundation.

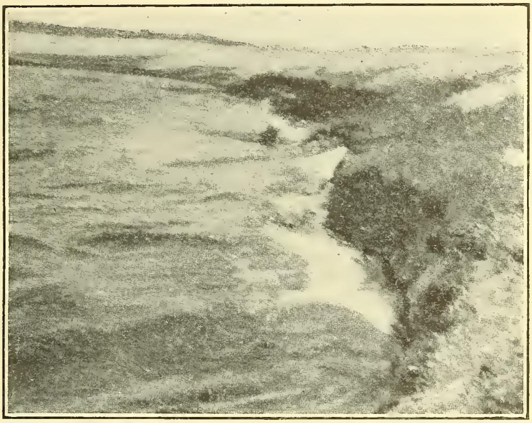

Fig. 23.—Erosive action of waves due to high winds.

COBBLESTONE AND MASONRY PAVEMENT.

The all-loose-rock or cobblestone slope protection as shown in Plate VIII, figure 2, consists of an 18-inch layer of cobbles placed on a similar layer of gravel If the cobbles were placed on the surface of the ground the continual pounding of the waves might displace them by washing out the earth beneath. This would let down the cobblestones into the holes formed by the waves, destroying the continuity of the surface and in time rendering the riprap useless.

Where the mortar is used between the cobbles the thickness of the layer of stone may be reduced. A slope protection commonly used consists of placing a 12-inch layer of cobblestones on a layer of broken stone of the same thickness. The spaces between the cobbles are grouted thoroughly with a cement mortar. To prevent uneven settlement and consequent cracking, such a paving should be laid only after a proper rolling of the slope and thorough seasoning of the embankment.

In Plate VIII, figure 1, is shown a view of a small reservoir at Auburn, Cal., which is lined with rough masonry. The wall is built of irregular rocks laid in cement mortar on a slope of about one horizontal to six vertical. Before placing a rigid lining of this sort the excavation or inclosure formed by embankments should be filled with water for some time, allowing a thorough settlement of all new material. A thorough tamping should then be given the slopes and bottom before placing any paving.

CONCRETE PAVING.

Some reservoirs are located in soils which are so porous that it is not economical or practicable to store water without some provision being made to prevent seepage. The use of concrete paving for this purpose is very satisfactory, but must be laid with proper care to

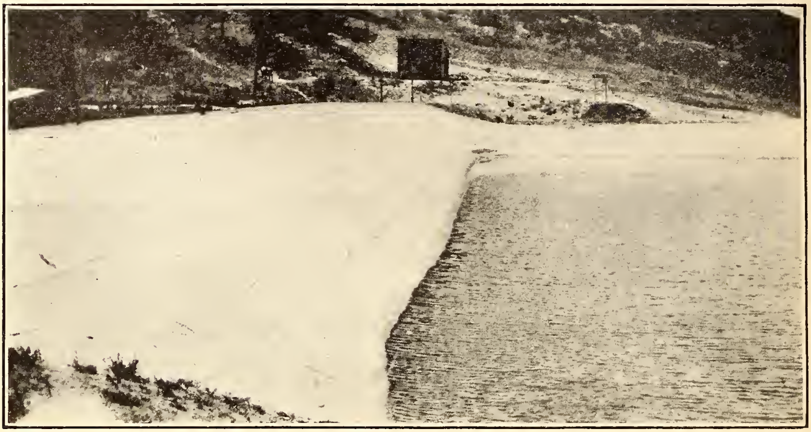

FIG. 24.—Concrete-paved slope, Silver Lake Dam, Los Angeles city waterworks, Los Angeles, Cal.

secure the best results. The precautions stated in connection with the placing of rubble masonry are also applicable to the placing of concrete. Concrete as ordinarily placed is usually from $2\frac{1}{2}$ to 5 inches thick and laid on a 3 or 4 inch layer of good gravel. In Colorado several reservoirs are being lined with reenforced concrete. This is rather an expensive lining for the ordinary reservoir, since the volume of the water stored will not justify a very large outlay of money.

In figure 24 is shown a view of the concrete-paved upper slope of the Silver Lake Dam, Los Angeles, Cal. This paving consists of 3 by 3 foot concrete slabs separated by layers of tarred paper. This manner of laying concrete was used to prevent fissuring, which might result in a monolithic coat consequent to the settlement of the dam. The smallness of the concrete slabs and the consequent larger number of joints which it necessitates introduce an element of weakness

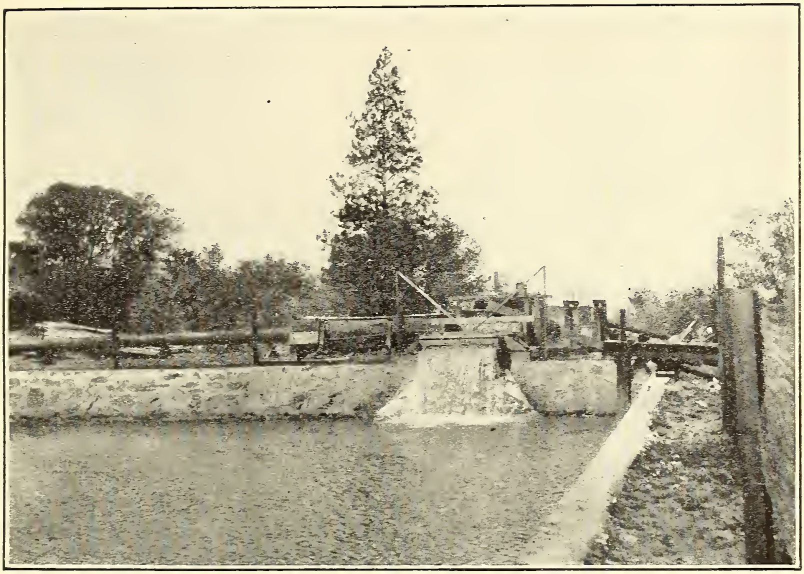

FIG. 1.—MASONRY-LINED RESERVOIR, CITY WATER SUPPLY, AUBURN, CAL.

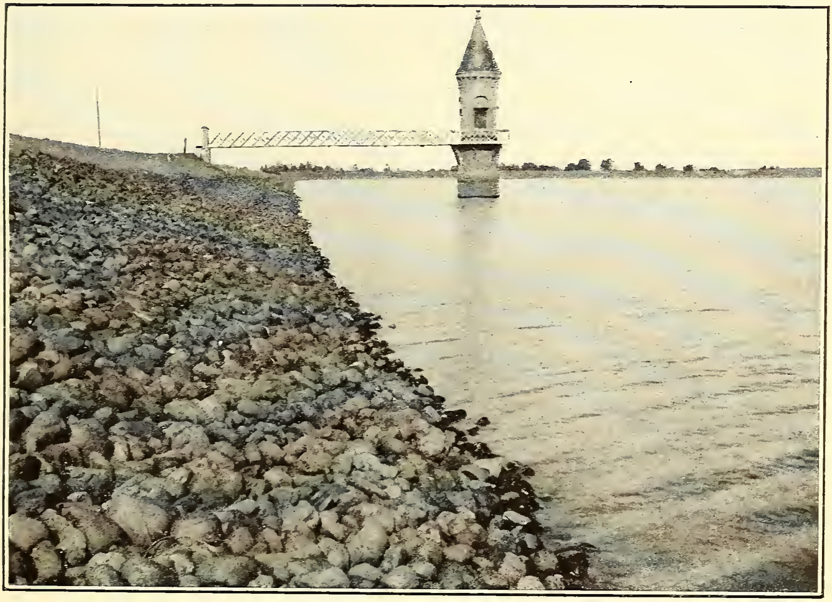

FIG. 2.—COBBLESTONE SLOPE PROTECTION, CITY RESERVOIR, MERCED, CAL.

which might have been partly eliminated if the lining had been cast in larger sections. The parallel lines in the figure are the tarred-paper joints running lengthwise of the dam. Those running crosswise can not be seen from this viewpoint. A thin coating of gravel was placed before the concrete was laid, as a considerable loss of concrete would have been incurred by ramming it into the bare earth.

The slope protection of the Terry Lake Reservoir, near Fort Collins, Colo., Plate IX, figures 1 and 2, illustrates the use of steel bars for the reenforcing of concrete linings. Before placing the concrete, the surface of the water slope was dressed off smooth and well compacted by moistening, rolling, and tamping. A trench was excavated 12 inches by 18 inches for a concrete foot wall to the slope paving. The thickness of the slope paving was 4 inches, reenforced with ¾-inch corrugated steel bars spaced 3 feet apart, parallel to the axis of the dam, and 2 feet apart at right angles to the same. All the joints were properly tied with soft iron wire. The top of the slope was provided with a concrete coping 6 inches wide and 12 inches high. The foot-wall and coping were tied together at intervals of 15 feet by traverse beams 6 by 8 inches reenforced with 2¾-inch corner bars. The coping is supported by concrete columns 12 by 12 inches, extending well below the surface of the embankment. The concrete for the slope was composed of four sacks of cement to 7½ cubic feet of sand and 15.2 cubic feet of gravel, the latter not exceeding 1½ inches in its greatest dimension. The cost of the concrete was about $1.33 per square yard of surface, with cement at $2.40 per barrel. The cost of the reenforcing steel was an additional 35½ cents per square yard f. o. b. cars at Fort Collins.

WASTEWAYS FOR RESERVOIRS.

IMPORTANCE OF PROPER DESIGN.

Every reservoir, irrespective of its size, should be provided with a wasteway or spillway sufficiently large to discharge without damage to the structure all the water which rises above the flow line. Many failures of dams may be traced directly to defective or insufficient wasteways during times of unusual floods. In reservoirs where the supply is derived from a spring, pump, flowing well, or canal, all of known capacity, the question of wasteway is a simple matter which involves little or no uncertainty. In the case of dams built in stream channels for the purpose of storing flood waters it is, however, often difficult to determine safe dimensions for wasteways. The area of the watershed above the dam site may be readily ascertained, but unless careful measurements of the run-off have been made for a long series of years, no accurate computations can be made of the volumes of water that are likely to pass the dam in times of floods.

Empirical formulas for maximum run-off are of little use, since no general formula can be made to apply to abnormal conditions. It is nevertheless true that the catchment areas of all important reservoir dams should receive careful consideration. Expensive wasteways should be apportioned and built only after a careful study of the character and topography of the drainage basin, the precipitation, the run-off, and above all, the extent and occurrence of floods. When all the available knowledge on these subjects is obtained, the wasteway may be designed to meet such conditions, but a very wide margin of safety should be allowed.

The proper position for a wasteway is a most important consideration. In overfall dams built of wood or masonry the entire crest is a wasteway in times of high water. The character of an earthen dam precludes its use in this way, although masonry wasteways are occasionally built in the center of earthen embankments. The usual and preferred practice, however, is to build the wasteway in the natural material at one end of the embankment. In order to keep clear of the dam the reservoir is tapped some distance above it, and the escaping water is conducted beyond its lower toe before it is discharged into the stream. Occasionally there will be a narrow ridge on one side of the reservoir site, with a natural saddle in it which will make an ideal position for the spillway, providing the cut is in a solid rock formation. Similarly, where one of the side walls at the end of the dam is composed of rock, a permanent wasteway can be made in this material. If composed of earth, some kind of impervious lining is required. It is not uncommon to build dams in stages, and under these conditions a temporary wasteway of wood may be used until the permanent structure is completed.

In the design and construction of all wasteways, whether permanent or temporary, it is important to bear in mind the conditions under which they are operated and the purpose which they are intended to serve. These by-pass channels take water from a state of rest in the reservoir, and after a short passage discharge it into the stream channel below, often at a high rate of speed. To do this economically, it is necessary to provide the wasteways with wide flaring intakes and to gradually decrease the cross section as the grade and the corresponding velocity of the water are increased. These channels must not only have ample width, but their depth must be such as to prevent at all times the overtopping of earthen dams.

A practice not unusual where reservoirs are used for irrigation purposes is to insert flashboards within the upper end of the wasteway in order to increase the capacity of the reservoir. This practice involves great risk to the structure unless a watchman is kept continually on the site with instructions to remove all flashboards before the occurrence of a flood.

FIG. 1.—PLACING STEEL REENFORCEMENT, TERRY LAKE RESERVOIR, COLO.

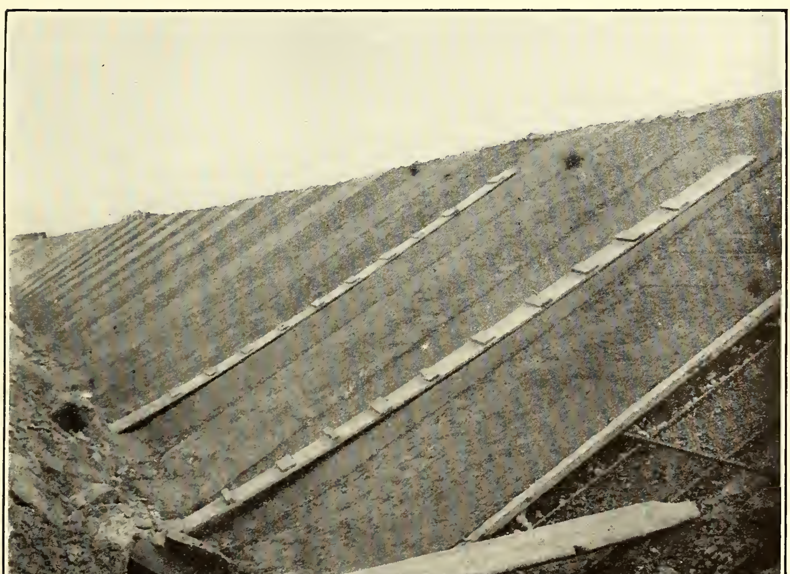

FIG. 2.—CONCRETE SLOPE LINING UNDER CONSTRUCTION, TERRY LAKE RESERVOIR, COLO.

TYPES ILLUSTRATED.

Several kinds of wasteways are briefly described and illustrated in the following paragraphs.

FOR SMALL RESERVOIRS.

The use of a standpipe constructed of vitrified sewer pipe properly supported makes a satisfactory wasteway for very small reservoirs. The diameter of the pipe will vary in size, according to the quantity of water supplied to the reservoir. The standpipe is placed with its top edge level with the flow line or high-water mark of the reservoir.

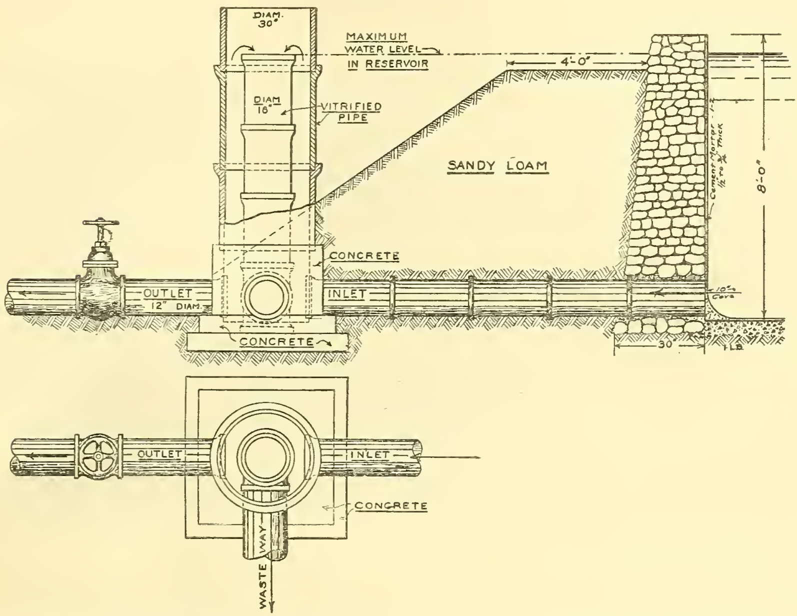

FIG. 25.—Combination outlet and wasteway, vitrified pipe, on reservoir near Pomona, Cal.

A combination of the type of wasteway just described and an outlet is shown in figure 25. The conduit leading from the reservoir may be built of either vitrified, cement, or cast-iron pipe. The water flows from the reservoir through this pipe and into the large standpipe. When the water rises in the larger pipe to the level of the flow line of the reservoir, it flows over into the top of the smaller standpipe through which it reaches the outlet channel. The flow of stored water is regulated by means of a gate valve placed outside of the larger standpipe.

In figure 26 is shown a temporary wasteway of timber in use at the East Canyon Reservoir, Utah. Figure 27 shows a spillway of concrete for a Colorado reservoir.

MAMMOTH DAM, UTAH.

A standard type of spillway is shown in isometric projection in figure 28. The spillway is that of the Mammoth Reservoir Dam, located in Sanpete County, Utah. It is excavated in the hillside at the north end of the dam and is practically a continuation of the structure forming the dam, the core wall of the dam extending to the south side of the spillway channel. This channel is of concrete 28 feet wide in the clear and 10 feet deep. A frame structure in this channel allows for the storage of 5 feet of water above the floor of the spillway by closing the three gates in the channel. The guides for these gates extend to a height of 5 feet above the walls, so that the gates may be lifted above the water when flowing bank full in the

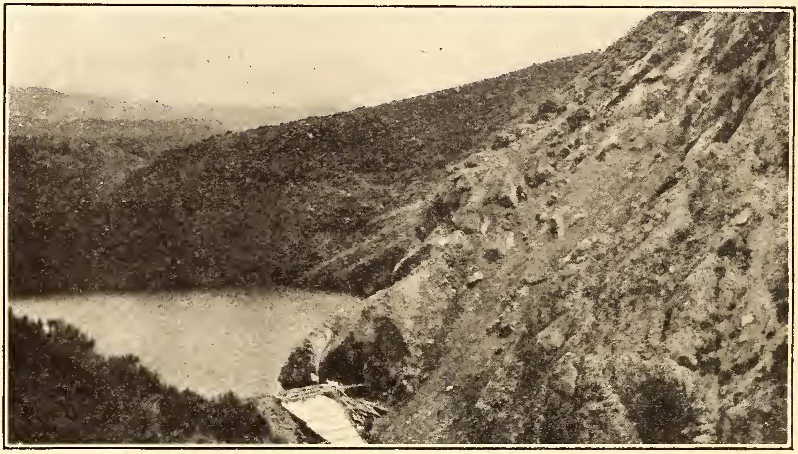

Fig. 26.—Wasteway of timber, used temporarily at East Canyon Reservoir, Utah.

channel. Water enters the concrete structure through an excavated earth channel 90 feet long and 28 feet wide on the bottom, with side slopes of 1 to 1.

Immediately after passing the gates the floor of the concrete channel takes a 5 per cent grade for about 80 feet, increasing by a vertical curve to a 25 per cent grade for about 300 feet, returning the water to Gooseberry Creek. The depth and width of the channel are diminished as the velocity is increased, due to the steep grade, being but 2 feet deep and 15 feet wide at the lower end.

SEVIER BRIDGE RESERVOIR, UTAH.

The spillway of the Sevier Bridge Reservoir, Utah, is well located and has a large safety factor. It is cut through a spur ridge in solid rock 200 feet from one end of the dam. The discharge tunnel and spillway were designed so as to permit of the washing out of all the reser-

voirs on the stream above without in any way impairing the safety and efficiency of the dam. It is 120 feet wide and will carry 6 feet of water. According to the specifications, its discharging capacity is 4,500 cubic feet per second. It has perpendicular sides, and bottom of solid rock. The waste water flows down over a rocky bank, returning again to the river, where it is caught by a diversion dam 60 miles below.

PHŒNIX RESERVOIR, CAL.

The two failures of the Phœnix Reservoir Dam, 5½ miles northeast of Sonora, Cal., illustrate the disastrous results consequent upon the building of spillways of inadequate size. In 1876 the dam failed, a heavy rainfall having caused the water to rise suddenly and over-

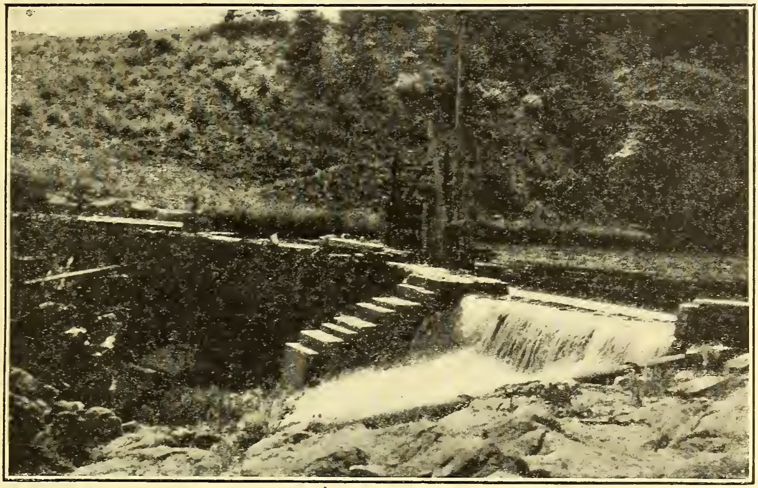

FIG. 27.—A small spillway constructed of concrete.

flow the dam, washing out the wooden spillway and also a large portion of the north end of the dam. The old spillway was replaced by one of concrete or masonry rubble. In the spring of 1906 it again proved too small to accommodate the surplus influx of water. As a consequence the flood water washed over the crest of the dam wear-it down and making a gap of 250 feet at the flow line. The down-rushing stream swept everything before it. Railroad and county bridges were destroyed for miles below the dam. The original portion of the masonry spillway was 73.6 feet long, containing three openings. The new construction (1906) has 60 feet additional length, containing two additional openings. The crest has an average width of 8.7 feet. The openings are separated by walls 3 feet thick which extend 6 feet above the crest of the spillway. In the older portion, the height of water was regulated by wooden slide gates operated by a

crowbar. The water level in the newer portion is regulated by flash-boards 3 by 12 inches. Plate X, figure 1, gives a view of this spillway from the lower side.

The spillway is built on a circle of 232.1 feet radius, with the convex face upstream. This is a very acceptable type if provided with suitable gates which can be operated quickly in time of sudden storm. The water drops from the spillway to solid rock and returns to its natural channel.

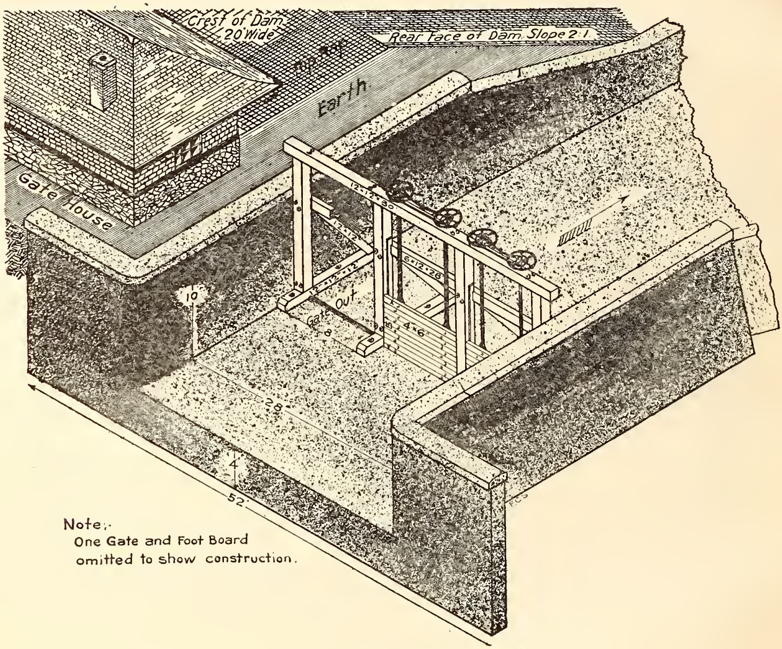

FIG. 28.—Isometric projection of spillway of Mammoth Dam, Sanpete County, Utah, showing concrete channel adjoining crest of dam.

SMALL LINED RESERVOIRS.

Small reservoirs which are built to store water furnished by pumping plants or to act as equalizing basins between the latter and distributary systems frequently present problems of an entirely different nature from the larger storage basins. The same is true to a less extent of small reservoirs which impound the waters of springs and creeks. Ordinarily, very little latitude is permissible in the selection of a site in such cases, as for obvious reasons the reservoir must be located near the pumping plant or other source of supply. Reasons which ordinarily govern the choice of site, such as economical construction because of natural contour lines, or proper conservation of the stored water because of a more or less impervious soil

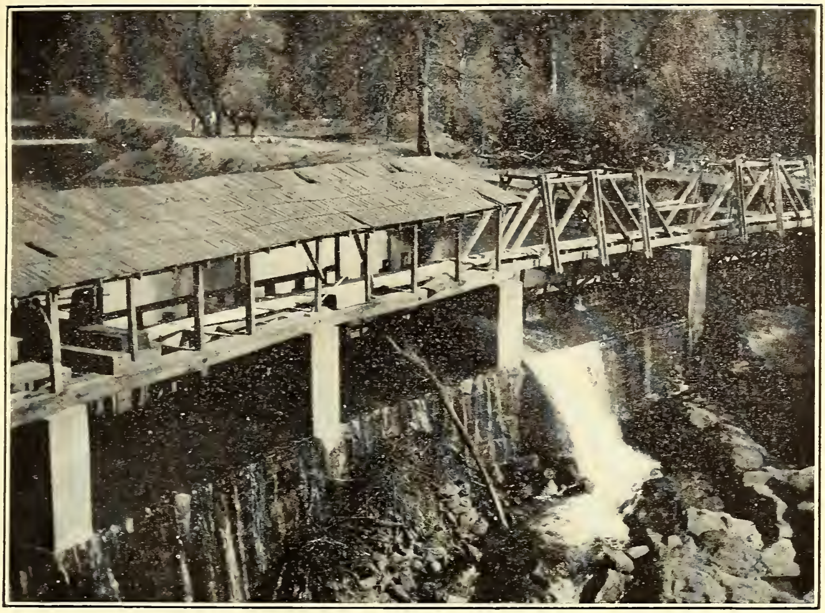

FIG. 1.—SPILLWAY, PHOENIX DAM, SONORA, CAL.

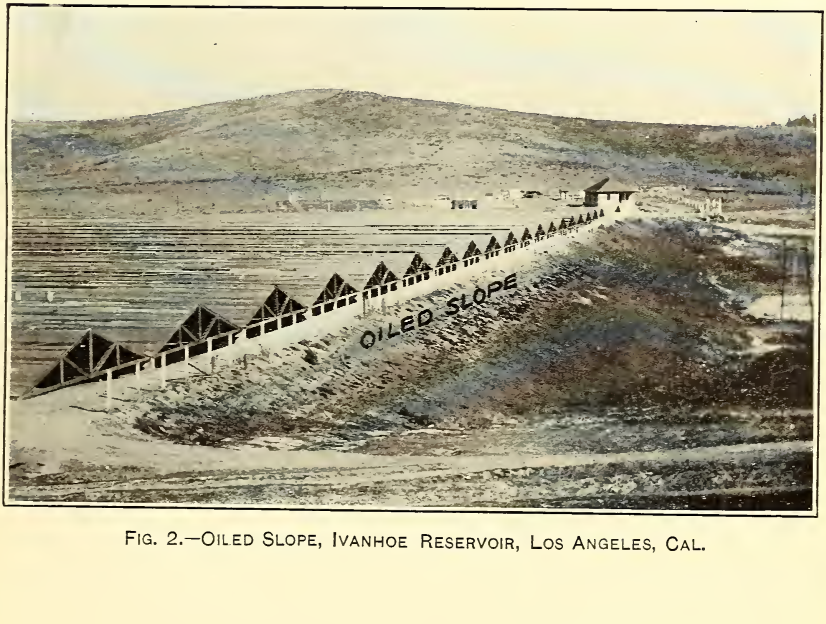

FIG. 2.—OILED SLOPE, IVANHOE RESERVOIR, LOS ANGELES, CAL.

on the bottom and sides of the reservoir, must here give place to the one essential reason of location near the source of supply. Such reservoirs are quite frequently built wholly in embankment, thus increasing the cost. They are likewise frequently built on ground which is too porous to retain water and must be artificially lined.

The extra cost due to poor location can not well be overcome, but the loss of stored water by seepage through the bottom and sides of a reservoir can be partially or wholly prevented by lining.

PUDDLED CLAY LININGS.

In the cheaper kind of small reservoirs, where clay is available, a coating of clay and gravel is often used to prevent excessive seepage losses. The clay is spread over the bottom in a layer varying from

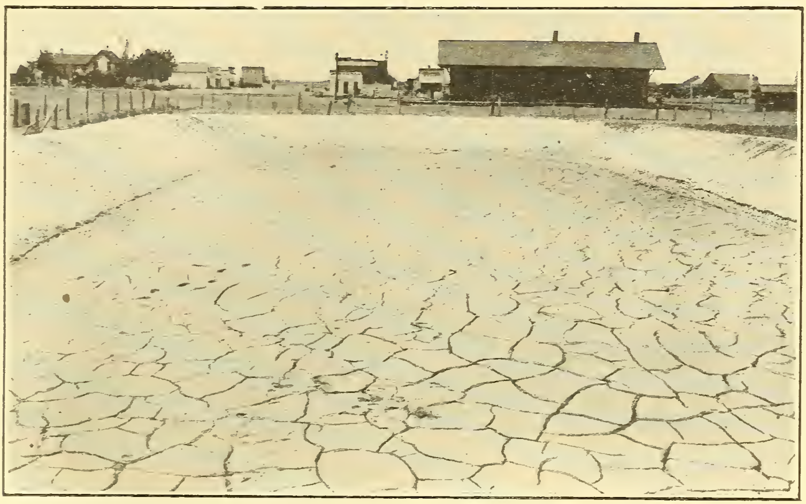

FIG. 29.—Effect of drying upon clay lining of reservoir at Eads, Colo.

3 to 6 or more inches, the surface moistened, and the whole thoroughly puddled. The puddling may be done by team and implements, but it is much more effective when a band of sheep or goats can be used. If water is to be used for irrigation purposes only, the floor of the reservoir may be used temporarily as a feeding ground for sheep.

The use of clay alone for the purpose of puddling is not recommended, as large sun cracks develop when the water is removed from the reservoir and the bed allowed to dry out. This is shown in figure 29, which represents a small reservoir used to store water from a pumping plant at the experiment farm of this office at Eads, Colo. After the clay has been thoroughly worked, gravel should be sprinkled over the surface and tamped into the clay, either by bars or by the feet of animals.

LININGS OF COAL TAR AND CRUDE OIL.

Coal tar has been used successfully in the lining of small reservoirs. At the experiment farm above referred to, 8 barrels of tar were used to cover the banks and bottom of a reservoir 50 by 100 feet, 4 feet deep, with sides built on a slope of 1 horizontal to 1 vertical. The soil was first thoroughly raked, so as to have a mulch of about 1 inch. The tar was warmed just sufficiently to allow it to spread. It was applied by means of an ordinary galvanized bucket with perforations made in the bottom. The cost of the tar f. o. b. Eads was $56, labor, $6; total, $62.

It was found that the above method produced a more satisfactory lining than by applying the tar boiling hot. The latter method produced a very hard lining which held water perfectly and required less coal tar, but during the winter months the action of the frost on the soil underneath caused the lining where exposed to bulge and crack. The sun then warped the pieces and destroyed it. On the bottom, however, where this lining had more or less water over it all winter, it did not bulge or crack, and made a very satisfactory coating. Where the tar was only slightly warmed, as in the method first mentioned, the lining was more rubbery and permitted of more expansion by frost and bulging of the soil underneath.

In southern California, oil has been very profitably used to form an impervious coating and also as an aid to protection from wave action for the slopes of small reservoirs. Instances can be cited in which reservoirs, whose embankment slopes would allow the water to seep out as fast as it came in, have been made to hold water with a comparatively small loss from seepage by properly applying crude oil to the slopes.

At the Ivanhoe Reservoir (Pl. X, fig. 2), with slopes 2½ to 1, oil was effectually used for paving purposes. The slopes were harrowed to a depth of about 6 inches, and reasonably clean sand was sprinkled over the harrowed surface to a depth of 1½ inches. A tank of oil was hauled along the crest of the dam and the oil sprinkled over the sand by means of a hose and hand sprinkler. A second coating of sand 1½ inches in depth was placed and oiled in the same manner as before. The oil was then thoroughly raked in and rolled by hand rollers. The summer heat was sufficient to warm the oil thoroughly. About 1,400 gallons of oil per day were applied. This was accomplished by 3 men, 2 oil wagons, 4 mules, and 1 driver. One wagon hauled oil while the other was being emptied. The oil used had a specific gravity of 16° to 18° (Baumé scale), and about 2.3 gallons per square yard were applied to the slopes.

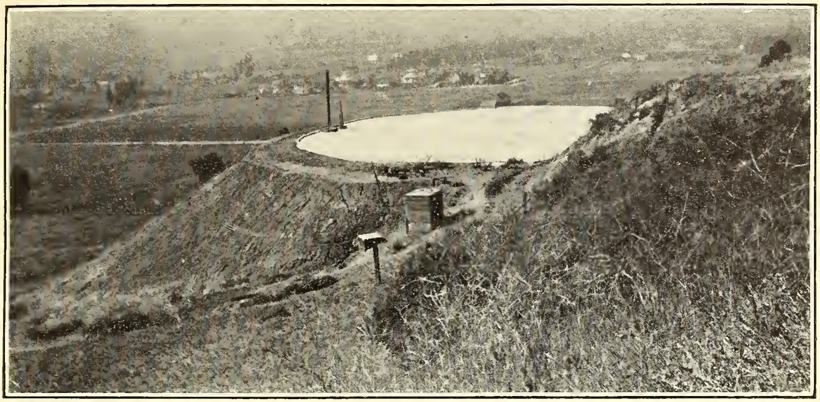

FIG. 1.—RESERVOIR BUILT ON SIDEHILL, WHITTIER, CAL.

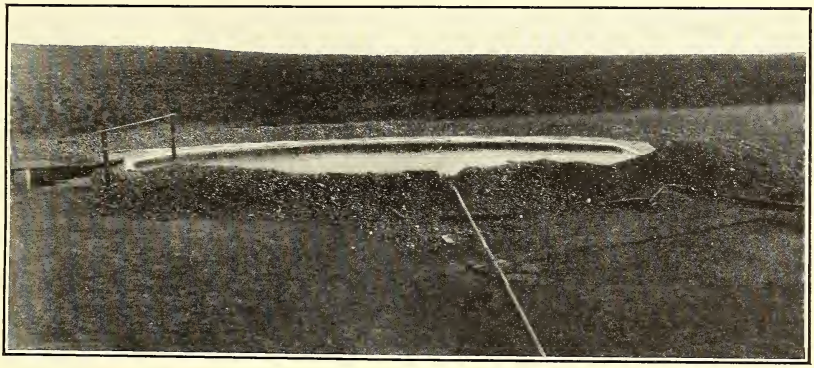

FIG. 2.—SMALL CONCRETE-LINED FARM RESERVOIR, EPHRATA, WASH.

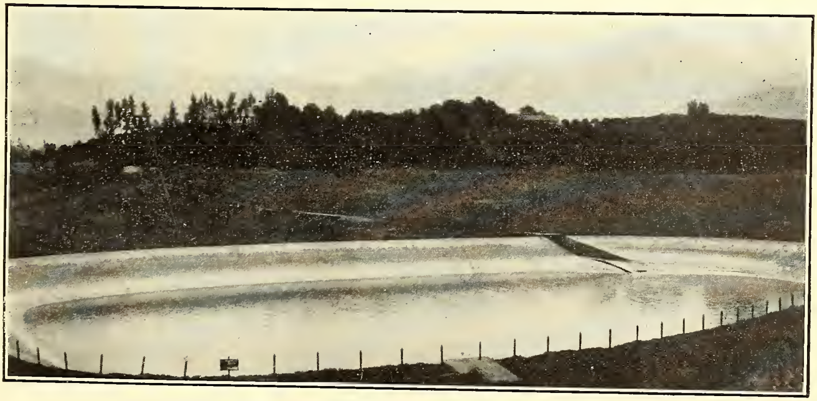

FIG. 3.—EQUALIZING RESERVOIR, REDLANDS, CAL.

CONCRETE OR MASONRY LININGS.

The linings heretofore briefly described should be used only in cases where first cost is the prime consideration. For more efficient and durable lining, cement concrete is recommended. The cost of Portland cement is now so low that it is doubtful economy to make use of cheaper substitutes. When field or quarry stones can be had at low cost, small reservoirs may be lined with such material combined with cement mortar.

A few typical illustrations of small reservoirs lined either with cement, concrete, or rubble masonry are given in the following pages. The actual costs are given whenever possible. These will of course vary in different localities and at different times. The accessibility of suitable materials entering into construction, such as gravel and sand, is an important item. While the price of cement has decreased in recent years that of labor has greatly increased, and it is, therefore, doubtful if some of these structures could be duplicated to-day with the same cash outlay.

EPHRATA RESERVOIR.

The small reservoir shown in Plate XI, figure 2, was built by J. D. Beard, Ephrata, Wash., in 1907, at a cost of about $500. It is circular in shape and 80 feet in diameter, with a capacity of about 150,000 gallons. The excavation was 6 feet deep with 2½ to 1 slopes. The reservoir is lined with a 6-inch layer of concrete plastered with a mortar mixture consisting of 1 part cement to 2 of sand. A 4-horsepower gasoline engine and a 16-foot windmill raise water about 50 feet to this reservoir, the engine being used only when there is insufficient wind to operate the mill. The pump cylinder is 3¾ inches by 40 inches inside measurement, with 4-inch suction, and 3-inch delivery pipe to the reservoir. The gasoline engine operates the pump at 38 strokes per minute, 22 inches to the stroke. This supplies about 36 gallons of water per minute to the reservoir. The windmill has a 16-inch stroke and in a breeze of 15 to 20 miles per hour it will pump from 20 to 25 gallons per minute. This reservoir supplied 10 acres of land in garden truck in 1908, and all had sufficient water to make a good crop. It was emptied only twice during the season, but considerably more than this was used, as water was pumped into the reservoir continually during the season.

WHITTIER RESERVOIR, CALIFORNIA.

In Plate XI, figure 1, is shown a reservoir of 500,000 gallons capacity constructed on a sidehill, a portion of the structure being in cut and a portion in fill. The embankment is 14 feet wide on top, and

acts as a protecting wall around the lower side, the inner surface of the entire reservoir being covered with reenforced concrete. The depth of the reservoir is 13 feet 3 inches. The specifications called for a 1:3:5 concrete, reenforced in the lower half with rods every 6 inches, and every foot in the upper half. The floor was put in after all the walls were completed, and then a reenforced cover was put on. A trowel finish of 1:1 cement was used on the bottom and sides. A partition divides the reservoir into two compartments, facilitating the cleaning of one compartment while the other remains full of water. In order to drain out the water when cleaning the reservoir, the floors have a drop of 3 inches from the division wall to the side walls and a drop of 3 inches from front to back. Four 12-inch gate valves are used as outlets, two of which are used when cleaning. A 12-inch waste pipe is placed at the 12-foot elevation; this is the flow line of the reservoir. The water is supplied by pumping.

MONROVIA RESERVOIR.

An appropriate type of reservoir to be used on an irrigated tract of 100 to 160 acres is shown in Plate XII, figure 1. Its purpose, when so used, would be not only to equalize the flow between the pumping plant and the distributing system, but to afford a convenient storage, permitting of the more even and economical distribution of water and acting as an insurance against loss caused by a possible breakdown of the pump or engine.

The illustration here chosen shows the receiving reservoir of the city of Monrovia, Cal. Its capacity is approximately 1,500,000 gallons, or about 4.8 acre-feet. Its cost was $4,914. It is circular in shape, 150 feet in diameter, 12 feet deep, and is built one-half in excavation and one-half in fill, the excavated material being used for filling purposes. The embankment of earth is 6 feet wide on top, with vertical walls inside and 1 to 1 slopes outside. The reservoir is concrete lined, the wall being 12 inches thick at top and 20 inches at bottom, with the batter on the earth side. A footing extends out at the base of the wall and is made a part of the concreted floor. This floor is 6 inches thick and is laid on a well-puddled earth bottom. The reservoir is provided with a 16-inch outlet and a 12-inch inlet through sand box and weir box over the top of the reservoir.

The pumping plant which supplies this reservoir consists of a 100-horsepower motor and a centrifugal pump, with a capacity of 3 cubic feet per second, or 1,350 gallons per minute. The lift varies from 50 to 100 feet, according to the season. Running at full capacity it takes this motor and pump 19.6 hours to fill the reservoir. The cost of pumping plant, including 80-foot concrete-lined pit 6 feet in diameter, vertical centrifugal pump, house for motor, etc., was $6,500.

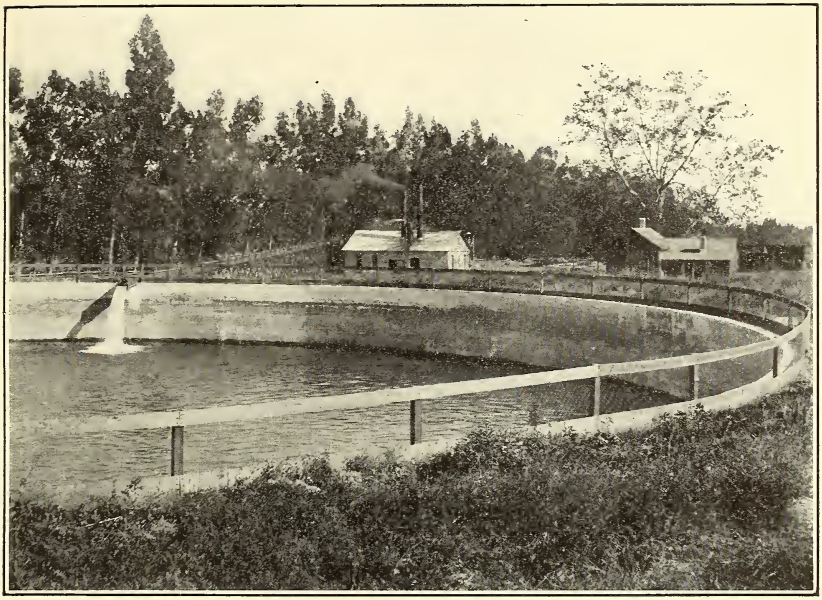

FIG. 1.—TYPICAL RESERVOIR, CITY SUPPLY, MONROVIA, CAL.

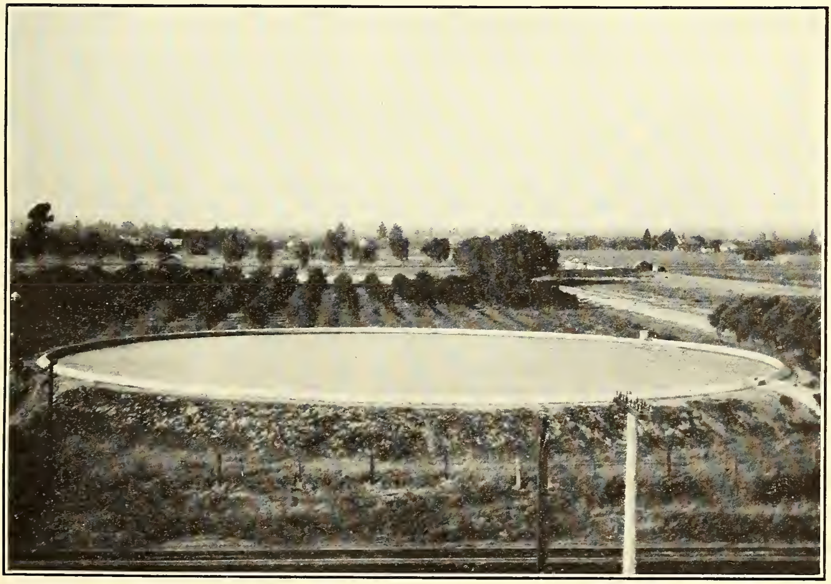

FIG. 2.—CONCRETE-LINED RESERVOIR, POMONA IRRIGATION CO., CALIFORNIA.

POMONA RESERVOIR.

The circular reservoir shown in Plate XII, figure 2, is located near the ice plant, Pomona, Cal., and has a capacity of approximately 1,750,000 gallons. It is 190 feet in diameter, 8 feet deep on three sides, sloping to a depth of 8½ feet at the outlet, the floor being laid so as to drain the water from the reservoir. A cobblestone wall, vertical on the inside, 18 inches wide on top, 30 inches wide on bottom, and averaging 9 feet high, was first built in a 190-foot circle. The mortar used in laying the cobbles was made as follows: A lime mortar, consisting of 1 part lime to 12 parts sand, was first mixed. To 4 parts of this mixture were added 1 part of cement. This mortar adhered to the round cobbles. Forms 2 feet high were made by nailing 1 by 12 inch boards to 2 by 4 inch uprights spaced 10 feet apart. After filling this portion the boards were raised another 2 feet. This form was used merely as a guide or template, and no pressure was brought to bear upon it. The bottom of the reservoir was covered by a 6-inch concrete floor which formed a rough joint with the walls. The first 5½ inches of this floor was a concrete of a 1:2:4 mixture, on top of which was placed a ½-inch trowel coat of cement mortar which was afterwards washed with neat cement. The joint between the floor and wall was finished by a 3-inch cove. This cracked and caused the reservoir to leak, after which a 10-inch cove was substituted. No further leakage from this cause occurred. An embankment of sandy loam 4 feet wide at the top with a 2 to 1 slope surrounds the cobblestone wall.

It took about three months to build this reservoir, the work being divided as follows: Four masons and 8 helpers, 10 days to lay up walls; 2 cement men and 18 helpers with machine, 30 days to mix the concrete and place it in the floor; 1 plasterer and 1 helper, 2 weeks to plaster reservoir. To cover the walls and floor with a neat cement wash required 3 to 4 barrels of cement. The contract price of this reservoir, with 1,400 feet vitrified pipe, was a trifle more than $7,000.

REDLANDS RESERVOIR.

In Plate XI, figure 3, is shown a cement-lined reservoir with a capacity of 3,000,000 gallons. This reservoir is the property of the Redlands Water Co. and is one of the important features in their distributing system, equalizing the fluctuations in the water supply, thus providing a steady flow in the pipe lines leading to the farms. Water leaves this reservoir through two 8-inch pipes which empty into a large box out of which a 12-inch pipe leads to a smaller box, where a 49-inch rectangular weir is installed.

WOOD RESERVOIR.

The small concrete reservoir shown in figure 30 was built on the farm of B. A. Wood, Syracuse, Kans. This reservoir is 40 by 40 by 4 feet inside measurement, and if filled within 3 inches of the top it has a capacity of 6,000 cubic feet, or enough to cover 1 acre of land 1.65 inches deep, not counting losses incurred in distribution. The walls

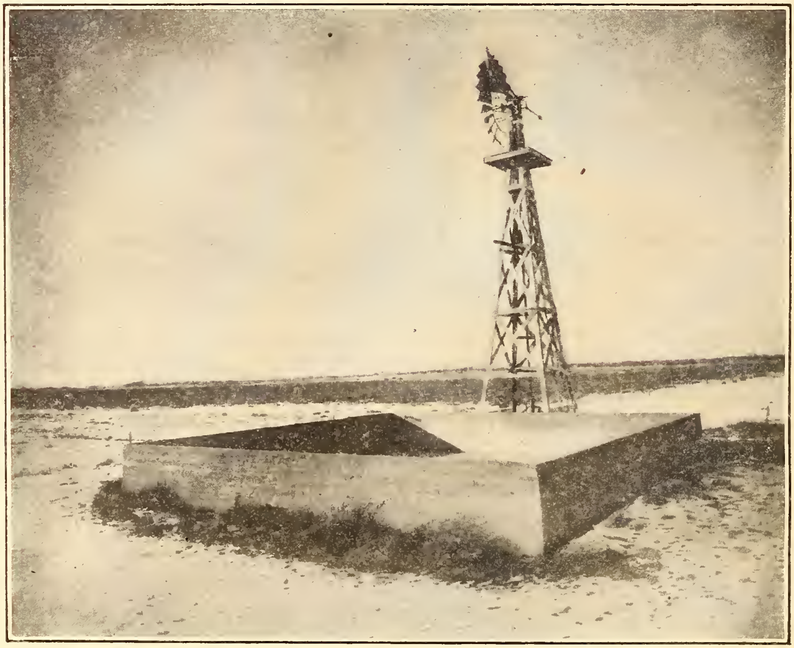

FIG. 30.—A simple type of concrete reservoir for a small water supply.

are set 6 inches under normal ground level. The corners are reenforced with numerous old wrought-iron rods, while the walls are reenforced with six strings of barbed wire extending entirely around the tank. The bottom is 4 inches thick. After the walls and bottom were completed the entire inside of the tank was given a wash coat with a 1:1 cement mixture. This tank has stood well, never having cracked.

HYDRAULIC-FILL DAMS.

INTRODUCTION.

The building of dams by the hydraulic method has an interesting origin. In the very early days of mining in California, gold was taken from the auriferous sands by means of sluice boxes containing mercury in the riffles. Into these boxes the sand was shoveled. This process was laborious and slow. Some one, however, evolved the idea of washing down the gold-bearing sand by means of powerful streams of water directed against the banks and hillsides. The sand-ladened water was passed through flumes to the sluice boxes, where the gold, being heavier than the sand, was caught by the mercury. During this process enormous quantities of sand were moved at a minimum cost to the miner, but in some cases the débris was deposited in streams, choking their flow and backing the water upon agricultural lands. In seeking to avoid such conditions the building of dams by the hydraulic method naturally originated. Small diversion dams were built at first with the débris from which the gold had been removed and used either for impounding small supplies of water or for holding back subsequent débris from the river bed. Numerous large dams have been built since by the same method to impound water for domestic and irrigation purposes. At first these dams were more or less of an experiment, but, with the results of many experiences to draw upon, the methods employed are now far superior to those first used, new ideas having been brought to light with new experiences.

In the following discussion will be considered—first, the relative merits of various suitable materials for hydraulic construction as to compactness, stability, and imperviousness; and second, the equipment needed and the constructive methods employed, with special attention to the requirements which apply particularly to hydraulic-fill dams. The reader will note that the subjects of slopes and slope protection, outlets and spillways, have been taken up under separate headings in the discussion of earth-fill dams.

In the selection of a site for a hydraulic-fill dam several features must be considered in addition to those generally involved in the choosing of a site for an ordinary earth-fill dam. The latter have already been fully considered. Of first importance where the hydraulic method is used is an ample supply of water. This is furnished either by gravity flow or by pumping. A flow of 2 to 20 cubic feet per

second generally will suffice. Sufficient head also is required to give the desired pressure. This should be from 40 to 75 pounds per square inch. Moreover, suitable material must be at hand, not only such as will give stability to the structure but such as may be readily sluiced into place; and, finally, this material must be available in sufficient quantities at a point not too far removed from the site of the dam to make transportation by the hydraulic method practical. These requirements will be discussed further in the following pages.

Where the above conditions are fulfilled there is a distinct advantage for the hydraulic method when compared with the ordinary method of moistening, rolling, and tamping. Not only are the desired selection, transportation, and distribution of materials accomplished with greater ease and certainty, but greater imperviousness and safety are secured and the cost lessened.

The hydraulic method, however, is not applicable to all dam sites, and construction should be carried forward only after thorough investigation and with due caution in order that the method be not misapplied. There have been cases where it was not the most economical, financially or otherwise; still, where the necessary requisites and conditions are favorable, it is the most practicable and satisfactory of all methods for assorting materials and placing them accurately in embankment form. The degree of stability secured under such conditions is, after all, the strongest argument in its favor, for the question is not only how cheaply an embankment can be built but also how well it can be built within reasonable limits. In other words, cheapness of construction should never be sought at the expense of weakening the structure.

MATERIALS SUITABLE FOR HYDRAULIC DAM CONSTRUCTION.

The combination of materials best suited to the hydraulic method has already been touched upon under another heading.[1] The degree of compactness and imperviousness obtained by this method as compared with the ordinary method of depositing in layers, moistening, and rolling also has been fully discussed in the same chapter. It was found that the material best suited for use in this method was a mixture of gravel, sand, and clay or silt with about 20 per cent of clay, or enough to form a good binder between the sand and gravel. These ingredients when deposited under water in their proper proportions form a most compact embankment and permit of good drainage during construction.

The relative position of coarse and fine materials in the cross section of an embankment must be given close attention in the case of

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[1] See chapter on "Character of materials," pp. 13–17.

the hydraulic as well as the ordinary earth-fill dam, although the hydraulic construction, in the opinion of the writers, permits of a more nearly homogeneous mixture throughout the section.[1] The rock, gravel, sand, and clay are placed in such a manner in the hydraulic fill that each will perform its characteristic function and thus add to the stability and imperviousness of the structure. The all-important question is as to the relative position and proportion of the ingredients.

In the previous discussion of earthen dams it was seen that the clay core was utilized to make the embankment impervious and that it was placed near the center of the dam or toward the upstream face. The heavier materials were disposed near the outer slopes, the larger rock being placed on the downstream slope to give weight where most needed. With the hydraulic method the practice of forming an impervious core and the same general distribution of materials are adhered to with the modification above noted. The method presents a most unique plan of distributing materials upon the embankment, as will be discussed more completely in the succeeding chapters, and at the same time a much more thoroughly built structure is obtained than by the ordinary earth-fill method.

A mixture of sand and gravel without clay is considered by many as unsuited to embankment construction. True, it is impracticable to attempt by the ordinary process of moistening and rolling or tamping to compact such an admixture sufficiently to make of it an impervious mass. By the hydraulic process, however, a combination of sand and gravel will be formed into a very dense mass, being drained rapidly as it is placed, and will ultimately make an embankment which is compact and impervious.

Mixtures of broken rock and pure clay are to be avoided entirely for the hydraulic process unless a very satisfactory underdrainage system is employed during construction. Clay is a treacherous material, as it swells considerably when wet, and gives up the water so gradually that unless the work of constructing the embankment proceeds slowly and proper drainage is secured the center mass of clay remains practically a fluid. In such cases, as the work progresses, the added weight on top causes the sides of the embankment to give way, letting out the fluid clay mixture through the breach formed. This is exactly what occurred at the Necaxa hydraulic-filled dam, in Mexico, on the morning of May 20, 1909. This dam (Pl. XIII, fig. 1) is 190 feet high, 54 feet wide on top, and 965 feet on the bottom; the upstream slope is 3 to 1 and the downstream slope is 2 to 1. The only materials available for construction were pure clay and broken rock, and it is questionable whether the hydraulic process should have been used. The rock and clay were so disposed as to make the central

[1] See also discussion, pp. 22-24.

third a core wall of clay and the outer portions of rock and clay. It was assumed that the rock would form a good drain, leaving a solid clay core wall. Such drainage did take place for a depth of 8 to 10 feet from the outer slope, leaving the clay between the rocks hardened and preventing further drainage. The central portion, however, remained in a semiliquid form, finally exerting a pressure which was sufficient to cause a partial failure (Pl. XIII, fig. 2) of the dam. If there had been more sand and less clay in the mixture of which the central portion of the dam was composed, the drainage would have been more complete and the embankment would have remained intact.

EQUIPMENT AND CONSTRUCTION METHODS.

REMOVING AND CONVEYING MATERIALS.

Under the most favorable circumstances the materials suitable for hydraulic-fill construction lie above the crest and are obtainable at either end of the dam. Materials thus located may be moved from both ends simultaneously, expediting the work and decreasing the unit cost per cubic yard. The water necessary to carry on the hydraulic process is generally brought in pipes or carried in flumes above the dam at a sufficient height to give a good pressure head, but occasionally it is impossible to get a gravity flow with sufficient head, and it then becomes necessary to pump the water.

The transporting capacity of flowing water is an important consideration in planning the hydraulic equipment. The best results are obtained by the utilization of 5 to 25 cubic feet of water per second, the weight of materials moved governing largely the quantity of water used. The following table gives a list of various materials and the velocities of water required to move them.

Transporting capacity of flowing water, according to calculations of Hopkins and experiments of Du Buat.[1]

Velocity per second.	Velocity per minute.	Velocity per hour.	Materials moved.
Inches.	*Feet.*	*Miles.*	
3	15	0.17	Just move fine clay.
6	30	.34	Lift fine sand.
8	40	.45	Lift sand coarse as linseed.
12	60	.68	Sweep along fine gravel.
24	120	1.36	Roll along fine pebbles, 1 inch in diameter.
36	180	2.05	Sweep along slippery, angular stones size of egg.
48	240	2.72	Move large shingle.
60	300	3.41	Erode soft schist.
72	360	4.09	Erode stratified rocks.
120	600	6.84	Erode hard rocks.

[1] A. Geikie, Text-book of Geology, London and New York, 1903, 4. ed., p. 491. J. C. Trautwine, The Civil Engineer's Pocketbook, New York and London, 1909, 19. ed., p. 577. See also Ann. Rpt. Isthmian Canal Com., 1908, p. 177.

Where the flumes or pipes are located high above the dam they are tapped at the most convenient place with 6 to 12 inch riveted-steel

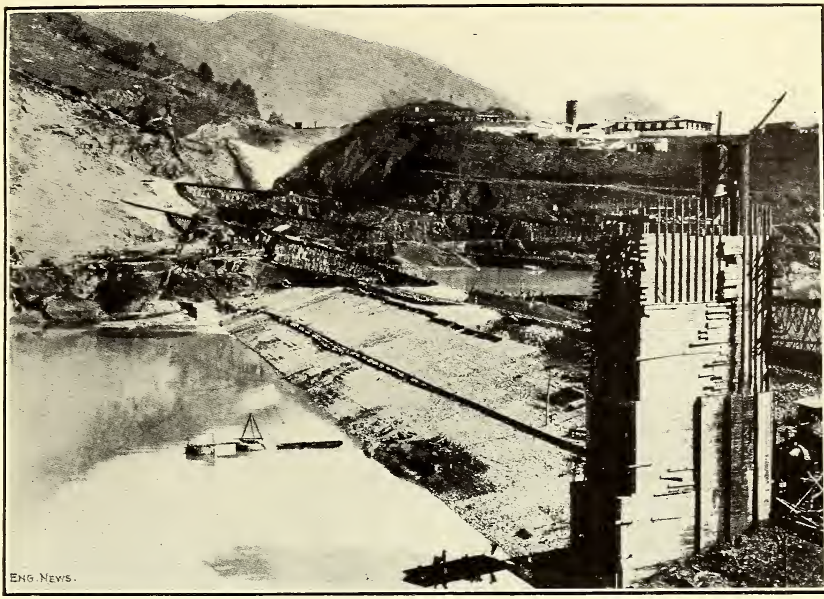

FIG. 1.—NECAXA DAM, MEXICO, DURING CONSTRUCTION. OUTLET GATES IN FOREGROUND. (FROM ENGINEERING NEWS, VOL. 62, P. 74.)

FIG. 2.—NECAXA DAM FAILURE, SHOWING DÉBRIS FORCED INTO RESERVOIR. (FROM ENGINEERING NEWS, VOL. 62, P. 74.)

pipe, which conveys the water down to where the hydraulic mining giants are stationed. These giants (fig. 31) are made of semisteel castings, upon which are fastened tapered riveted-steel pipes terminating in nozzles 2 to 10 inches in diameter. There is a ball-bearing joint where the two elbows join, so that the giant may be swung in a circle, thus commanding a larger area than the earlier stationary giants. A ball-and-socket joint just back of the union of the pipe and the casting permits of a vertical motion in addition. The box fastened on the end of the beam is filled with stones which balance the weight of the pipe and nozzle. By the addition of a deflector screwed on the end of the nozzle a stream of water under high pressure is readily directed against any portion of a bank. The "back kick" of the water, caused by turning the deflector against the stream, is utilized in swinging the giant in any plane. The pressure at the nozzle should be not less than 75 pounds per square inch

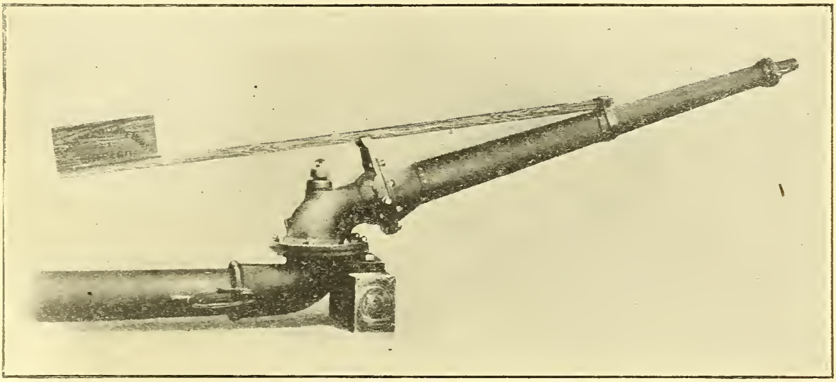

FIG. 31.—Double-jointed, ball-bearing giant used in hydraulic construction.

to be most effective, although lower pressures have been used with varying success. From 2 to 15 cubic feet per second of water are used in manipulating these giants. Their powerful streams are directed against the toe of the bank, as shown in figure 32, undermining it until a breast 10 to 30 feet and higher is reached. The materials are thus loosened and dropped into the stream of water flowing away toward the dam site. The mass of materials is best conveyed to the fill by open troughs built either of sheet iron or of wood. Plate XIV, figure 2, shows a sheet-iron trough used in the construction of the Croton Dam on the Muskegon River, Mich. These troughs were in 10-foot lengths, with a 30-inch semicircular section of No. 12 black iron, and cost $2\frac{3}{4}$ cents per pound, including bending, or $49\frac{1}{2}$ cents per linear foot of trough. In all, 850 feet of trough was used, and when lapped 6 inches and placed on an 8 per cent grade, it was water-tight without any calking or fastening at the joint. Wooden troughs were

tried at first, but were rapidly cut out by the grinding action of the materials carried. After four months' use on two separate works the iron trough showed but little wear. Two lines of the iron troughing, one on either side, were used in order to keep the center of the fill low, and the water was drained off at a point located as far as possible from the ends of the delivery troughs. The material moved consisted of fine yellow sand and was hydraulicked down by monitors of the type shown in Plate XIV, figure 1. These monitors consisted of heavy 4-inch rubber hose, fastened to a plank 2 by 12 inches by 12 feet, which was pivoted in such a manner as to be easily swung into any position. A nozzle 24 inches long, with a $1\frac{1}{2}$-inch aperture,

Fig. 32.—Monitor in action, Peasley Gulch, Cal., throwing stream approximating $1\frac{1}{2}$ cubic feet per second, from No. 5 centrifugal pump.

was screwed on at the end of the rubber hose. The same figure illustrates the manner of undermining the toe of the slope, caving down the top, and washing everything before the stream The water was supplied through a long line of spiral riveted pipe under a pressure of 100 pounds per square inch.

DEPOSITING THE MATERIALS IN THE EMBANKMENT.

There are at least three distinctive methods of depositing materials in embankments, using water as a conveying and consolidating medium, all of which may be classed under hydraulic or semihydraulic construction. These methods are: (1) Depositing in embankment form directly, by flumes or pipes, materials which have been loosened either by a hydraulic giant or by ground sluicing; (2) hydraulicking materials from slopes into a catch basin and then pumping the sluiced

FIG. 1.—SLUICING FOR CROTON DAM, MUSKEGON RIVER, MICH., SHOWING BEAMS BY WHICH NOZZLES ARE DIRECTED. (FROM ENGINEERING NEWS.)

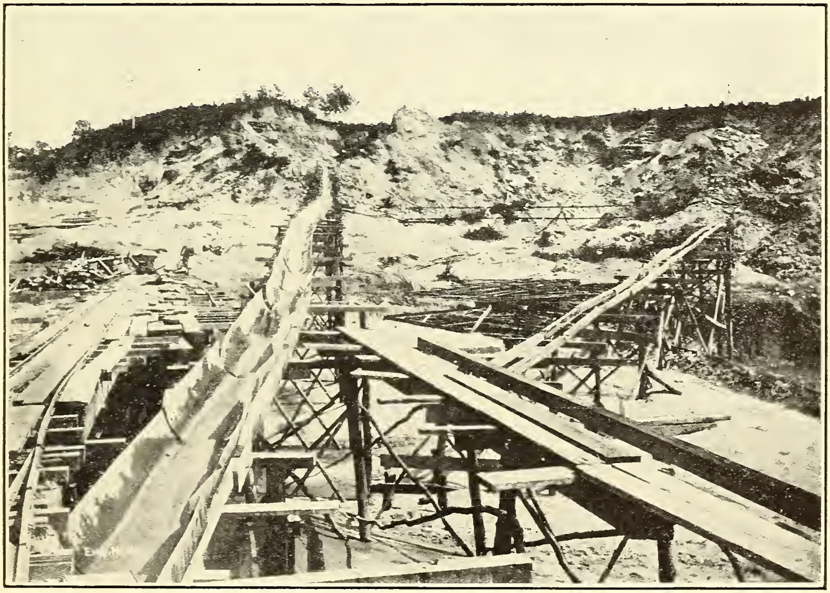

FIG. 2.—SHOWING SHEET-IRON TROUGH USED FOR TRANSPORTING MATERIALS, CROTON DAM. (FROM ENGINEERING NEWS.)

materials from the basin to the embankment; and (3) depositing materials under water confined between two small embankments previously built up by scrapers or dump cars and kept at a sufficient height above the confined water to prevent a break. This method might well be termed the basin method of hydraulic-fill construction.

The first method is the one most generally in use. The sluiced materials, having been brought to the dam, the practice is to start the work of filling in simultaneously from the upper and lower toes of the embankment. The material is commonly conveyed in flumes or pipes directly to the embankment and deposited at the outer edges of the fill, which are kept higher than the central portion, and allowed to run toward the center, care being exercised to keep the water well drained from the lake thus formed between the two slopes. In this way the heavier materials grade gradually from the coarse at the outer edges to the fine at the center.

The manner of placing the materials just described should, in the opinion of the writers, be modified to some extent. Some clays are so "fat" as to give up the water of saturation very slowly, and a large portion of the central mass of a hydraulic dam built according to the above method often consists of clay or silt of this nature. To eliminate this feature it is believed that better results will be obtained by distributing the coarse materials more generally through the cross section and still use the very heavy and large materials on the slopes of the embankment. If practicable, large rock can be dumped upon the slopes as they become settled, giving additional weight and stability and also protection against wave action. A more immediate drainage is obtained for the central portion of the fill by the latter method, the clay and sand settling firmly and closely about the larger materials and forming a very impervious structure.

When suitable materials can be obtained only at levels below the crest of the dam, the second method above mentioned is employed. The materials are sluiced to a basin below the dam and then delivered upon the embankment by means of a sand or dredge pump.

When there is only a small supply of water available the basin method has an advantage over the other methods mentioned. This is practically the same method as one of those described under "Earth-fill dams," pages 23, 24, where an ordinary earth-fill dam with a core wall was built by the use of a puddling canal. Two slope embankments are built across the canyon, one at the inner and one at the outer toe of the dam, the space between them being filled about two-thirds full of water and the materials being dumped into this canal from either slope. This method has been used on all sizes of dams, and the results obtained equal those obtained by the sluicing methods.

Another method which may be used where there is a scanty water supply is really a modification of the sluicing method. Settling

basins are built at one side and the water carrying the materials to the embankment is carefully drained off and carried to these basins. After settling, this water is used over and over again, being delivered under pressure to the point where the materials are washed down and then used to carry the materials to the embankment. This method was used on the Northern Pacific Railway in making some large fills.

A third method by which the water supply is conserved is the same as that employed at the Arrowhead Dam, described further on page 92, and is really a modification of the basin method. The material is loosened by blasts and loaded into dump cars by steam shovels or carried to the embankment in scrapers, the distance of haul, in either case, determining the method of transportation. Two slope embankments are built across the canyon, as described in the basin method. The inner slopes of these embankments or the ones facing the central portion of the dam are maintained as steep as possible. A hydraulic jet is then played against them, carrying the clay, coarse sand, and gravel into the core of the dam. In this manner the same results are obtained as in sluicing the material through flumes or pipes, but the amount of water required is very much less.

THE ORDINARY SLUICING METHOD ILLUSTRATED IN PRACTICE.

In the foregoing pages the general requirements pertaining to hydraulic-fill construction, and the different methods of furnishing a water supply, loosening the materials from the hillsides, transporting them to the dam site, and depositing them in embankment form have been discussed. There follow a few brief descriptions of the use of these methods in some of the larger and middle-sized structures in the West.

THE NORTHERN PACIFIC RAILWAY FILLS.

The low cost of the hydraulic process and its fitness for building embankments with steep slopes is well illustrated by the extensive hydraulic operations carried on by the Northern Pacific Railway in the Cascade Mountains, State of Washington, in the years 1890–1907. While the purpose of the work was to replace timber trestles supporting the railway tracks, over 20 such structures on the main line being replaced with earthen embankments, the identical methods are applicable to the construction of earthen embankments for irrigation purposes.

Most of the trestles were located in heavily timbered country where forest fires threatened their destruction at almost any time. The materials available consisted of loam, sand, gravel, and some large bowlders. All these materials were easily moved, but were not always plentiful where desired.

THE WATER SUPPLY.

In order to furnish an adequate water supply for this undertaking water was carried in a flume above the work on a minimum grade of one-half inch per 16 feet for a distance of 8 miles on the west slope and 5½ miles on the east slope. This water-supply flume was built of 1½-inch lumber, 14 and 16 inches wide, making the completed flume 14 inches wide on the bottom and 14½ inches deep (inside measurements). It was built in sections 16 feet long and cost 10 cents per linear foot, using common labor. At first the flume was placed on the ground which oftentimes was graded to accommodate it. This method proved a failure, as the heavy snows crushed the timbers and rendered the flume entirely useless. It was afterwards rebuilt upon bents averaging 4 and 5 feet high and spaced 8 feet apart. The cap of the bent was a 2 by 6 inch timber, laid flat, so as to form a support for two abutting ends of flume sections. Wherever a monitor was to be used a 16-foot section of flume connected with the main flume, tapping it and conveying the water into a box 8 feet square by 10 feet deep, the box being in turn tapped at the bottom by a 9-inch straight, riveted, slip-joint pipe. This pipe was made of No. 16 (B. & S. gauge) sheet steel, with 4 lugs riveted near each end of a section by which the sections were held together with wire. The sections were made in such lengths—20 and 22 feet—that they could be easily handled. A special feature of this type of pipe is that it can be used on the most rugged slopes owing to the readiness with which it conforms to the natural slope of the ground. A monitor in action washing down materials for the fill in bridge No. 184 is shown in Pl. XV, fig. 1.

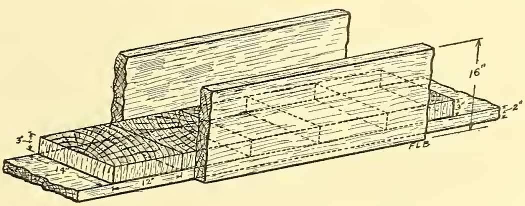

Fig. 33.—Type of sluice box used on Northern Pacific Railway hydraulic fills.

TRANSPORTING THE MATERIALS.

To carry away the materials thus loosened a supplementary stream of water was furnished by a 5-inch hose, as the stream from the giant was not sufficient for this purpose. (See Pl. XV, fig. 1.) The materials were caught and carried in a wooden flume 14 by 16 inches inside measurements. The bottom of this flume was paved with blocks 3 inches thick (fig. 33) sawed from old 12 by 14 inch bridge timbers. These were laid with the grain of the wood in vertical position, presenting a good wearing surface. It was found that the block lining wore sufficiently long to permit the passage of 55,000 cubic yards of materials before having to be replaced. The flumes when

operated under ordinary conditions were filled to within 2 inches of the top with water, gravel, and débris which were being conveyed to the bridge embankment. The grade on which the flumes were built was not less than 3 per cent and in some cases, where obtainable, was as high as 5 per cent. The sluiced materials were run through the boxes to the trestles and dropped from the upper side as shown in Plate XV, figure 2.

DEPOSITING IN EMBANKMENT.

Levees of dry earth and straw were built to retain the deposited materials on a slope of $1\frac{1}{2}$ to 1. After the materials were deposited on the embankment the flow of the liquid mud was directed by movable dams, as shown in figure 34. These dams consisted of 2 by

FIG. 34.—Retaining levee of brush, straw, and earth, also movable dams directing flow of mud, Bridge No. 183, Northern Pacific Railway.

12 inch planking 12 to 16 feet long, held on edge by 2 by 4 inch strips, as shown in the figure. These dams could be placed so as to direct the flow of materials to any part of the embankment and also prevent an overflow and tearing out of the levees. The $1\frac{1}{2}$ to 1 slope is exceptionally steep for a hydraulic fill and is not at all practicable for reservoir construction, it being more advisable to use a slope of 2 to 1 or 3 to 1 for the latter. In the case of the railway fills, however, the $1\frac{1}{2}$ to 1 slopes serve the purpose for which they are built and also show what extremes are possible with the hydraulic method.

After the materials in suspension were sufficiently settled the excess water was carried away in waste flumes or boxes 12 by 18 inches

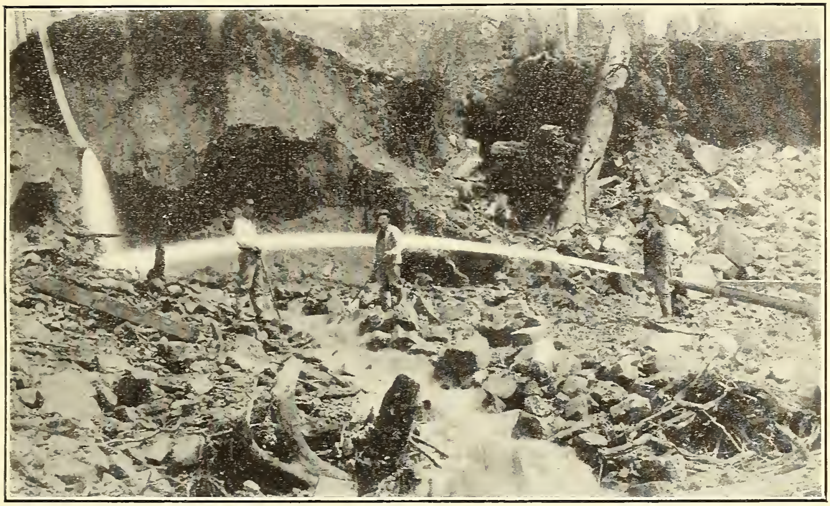

FIG. 1.—SLUICING FOR BRIDGE NO. 184, NORTHERN PACIFIC RAILWAY, SHOWING SUPPLEMENTARY STREAM FOR CONVEYING MATERIALS.

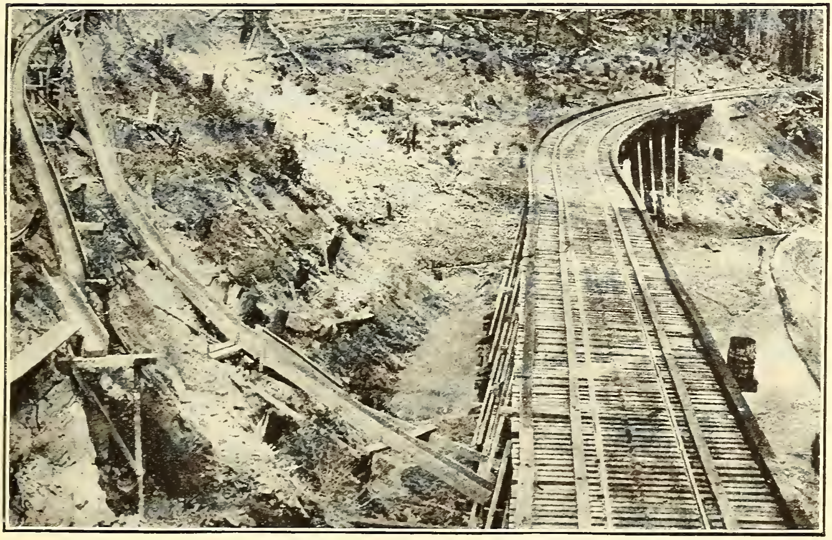

FIG. 2.—BRIDGE NO. 183, NORTHERN PACIFIC RAILWAY, SHOWING LOWER SLOPE AND RETAINING LEVEE, ALSO FLUMES FOR CARRYING MATERIALS TO EMBANKMENT.

inside measurements. One portion of the flume extended vertically down through the embankment, intersecting another flume of the same size placed along the natural slope of the ground. The vertical portion of the flume had three sides to start with, the fourth side consisting of short, narrow pieces nailed on horizontally as the work progressed. The level of these short pieces was kept below that of the side levees, thus preventing the water from rising too high and escaping over the levees.

COST OF THE WORK.

The close relation between distance over which the materials are carried and the cost per cubic yard is well illustrated by this work. At bridge No. 182, located on a rocky cliff 3 miles west of Stampede, Wash., the materials in the immediate vicinity were very scarce and had to be carried in a flume from a point $1\frac{1}{2}$ miles from the work. This material consisted of black loam with some gravel, and was taken from an old switchback southwest of the bridge. This work cost 3.7 cents per cubic yard.

At bridge No. 181, located about 1,000 feet from No. 182, there was a "pocket" of earth at the end of the bridge. Only 60 feet of flume was necessary in this case, so that with six men about 4,200 cubic yards of materials were moved at a cost of 2.5 cents per cubic yard.

The scarcity of water above the dam site is another important item influencing cost. At bridge No. 191 water was so scarce that it was necessary to pump from a system of settling tanks, the water being drained from the embankment, returned to the tanks, and pumped over and over again. The object of having more than one tank was to have the water as free from sediment as possible when it was repumped. The water was elevated 300 feet by a duplex pump and a single-stroke pump working together on the same pipe. This embankment cost most of all, the price being 13.5 cents per cubic yard. This was due to the scarcity of material at the bridge and the additional use of a pumping system. The material moved was principally shale rock mixed with very little earth, and a large area had to be stripped in order to obtain a sufficient amount to make the fill. The above data and illustrations were furnished by Grant Gibson, superintendent tie-preserving and tie-treating plants of the Northern Pacific Railway, who directed the work upon these fills.

CHICAGO, MILWAUKEE & PUGET SOUND RAILWAY FILLS.

An interesting method of sorting materials and placing in embankment form, as well as furnishing a water supply in V-shaped timber flumes, illustrating again the adaptability of the hydraulic process

to a rough and inaccessible mountain district, was employed by the Chicago, Milwaukee & Puget Sound Railway Co. in the building of several fills along its line. The methods used are equally applicable to the building of reservoir embankments which store water for irrigation purposes.

This work is located on mile 15, Snoqualmie district, main line of the Chicago, Milwaukee & Puget Sound Railway, near the upper falls of the South Fork of the Snoqualmie River, in King County, Wash., about 40 miles east of Seattle. The railway here traverses a very steep hillside at a distance of about 700 feet above the river bed. The line is crossed with deep-cut ravines, which make a short movement of materials possible. The sides of these ravines are very steep, the slopes ranging from 35° to 45°. The material composing these slopes was a glacial drift consisting of sand and washed gravel, intermingled with some large bowlders and occasional streaks of sand and gravel bearing a percentage of clay.

Topographers Gulch is the most westerly of three large fills placed by the hydraulic method. This fill has a length of 800 feet at the grade line, a maximum height of 282 feet, a maximum width of 706 feet, a roadbed width of 30 feet, and contains 632,000 cubic yards of materials. The height given is from the toe of the slope to the top of grade, and the maximum width is the distance between toes of slopes. The slope of the fill was $1\frac{1}{4}$ to 1.

THE WATER SUPPLY AND SLUICING.

The water supply was obtained by building a rock-filled crib dam at a narrow gorge in the South Fork of the Snoqualmie River about 1 mile above the gulch. The water was carried from this dam to a penstock in a V-shaped flume built on low bents. (Pl. XVI, fig. 1.) A section of this flume and a bill of materials for 100 linear feet of the same are given in figure 35. The triangular form was adopted as it was thought that a flume of this type would be more easily built, curved, and kept water-tight than a rectangular one. The penstock was a 38-inch wood-stave pipe and water was dropped 400 feet in a distance of 800 feet to a battery of four impulse wheels, direct connected to a four-stage 16-inch turbine pump, which discharged water through a 24-inch riveted steel pipe (Pl. XVI, fig. 2), up the slope for a distance of 1,450 feet and 600 feet above the level of the pump to a three-way distributing box. From this box water was taken in 16-inch wood-stave pipes to the various cuts, where it was used in the hydraulic giants. For excavating and sluicing jets 6-inch and 4-inch rubber hose and plain nozzles $1\frac{1}{2}$ to $3\frac{1}{2}$ inches in diameter were used in all work. The pressure at the nozzles varied from 40 to 60 pounds.

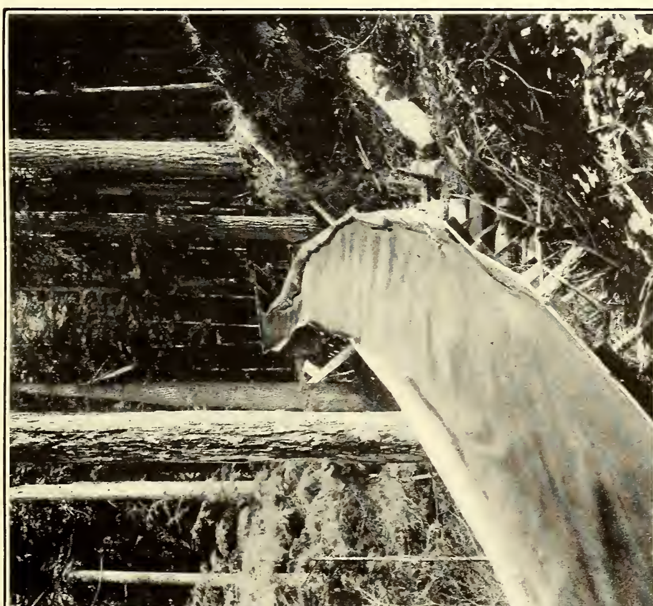

FIG. 1.—VIEW OF V-SHAPED FLUME FOR CARRYING WATER FROM DAM TO PENSTOCK.

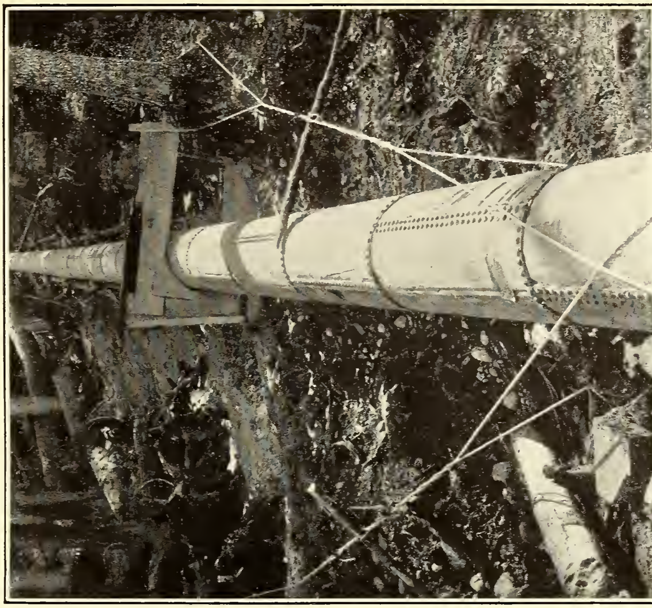

FIG. 2.—VIEW OF 24-INCH DISCHARGE PIPE, SHOWING METHOD OF ANCHORING SAME TO TREES.

DEPOSITING IN EMBANKMENT.

The materials were placed in the embankment so that the coarse gravel and rock made up the downhill slope, the sand and lighter materials being placed on the inside. These materials were segregated by the use of settling tanks, a side elevation of one of which is shown in figure 36. The débris from the giants entered a point designated on the figure as A, and was carried down a very steep slope over a grizzly, the rock and large gravel being taken out at B. The materials left were passed through the grizzly at C, where the remaining gravel was collected and passed down and out through the flume D. The sand and water were passed through the sand screen at E, the waste

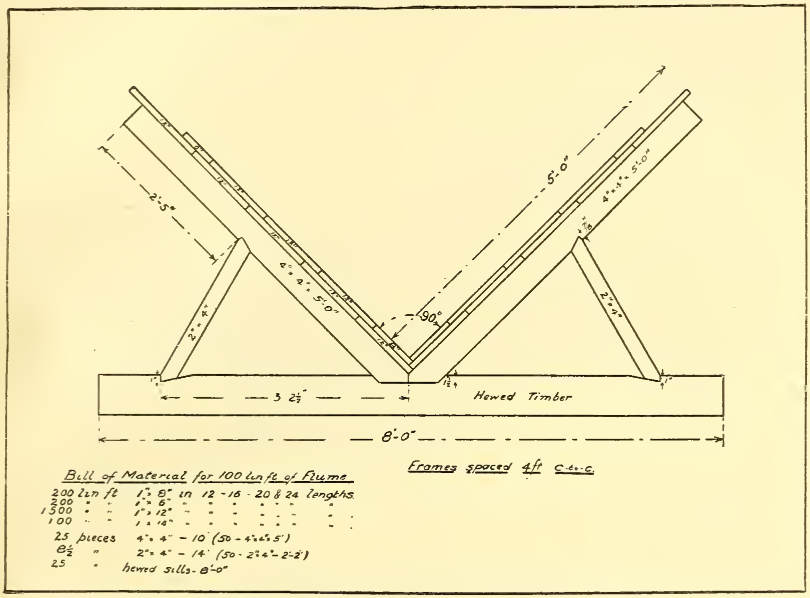

FIG. 35.—V-shaped flume used for carrying water to penstock.

water being carried out through the flume at F to the very toe of the slope, and the sand being passed through the spout at G into the settling tank and thence through the flume H to the embankment. The flumes carrying the sluiced materials to the embankment were lined with paving blocks, 4 by 8 by 12 inches, with the grain on end.

In order to hold the materials in embankment, brush dikes were built, starting at the lower side of the fill, similar to those shown in figure 37, page 81. Posts, 3 to 5 feet long, were driven so as to leave the tops about 2½ feet above the surface in the line where the dike was to be built. These posts were spaced about 8 feet apart. Long poles were laid lengthwise on the upper side of these posts and sand washed up against them to support them. Green boughs were then

laid against these poles with the butt end up and to a sufficient depth to prevent sluiced materials from passing between the poles. The amount of brush used depended upon the fluidity of the materials held. "Chimney" drains were used to carry off the surplus water from behind the dikes after the materials had settled (fig. 37). This water was carried to the toe of the slope in flumes before being allowed to run free.

SUMMARY.

The materials moved amounted to 890,000 cubic yards of which 632,000 were used at Topographers Gulch. About 8,400 gallons of water per minute were used at the giants to tear down the materials. The rated capacity of the pump, with 80 pounds per square inch

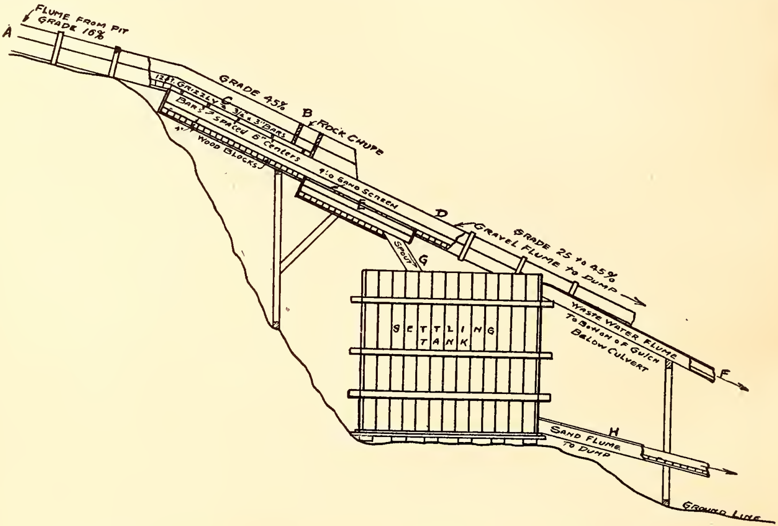

FIG. 36.—Side elevation of settling tank and distributing flumes.

nozzle pressure, was 7,000 gallons per minute, but it was found that 40 pounds nozzle pressure was sufficient and with that pressure the pump delivered 8,400 gallons per minute. The duty of water or ratio of solids to amount of water used was 5 per cent, that is 20 cubic yards of water were required to move 1 cubic yard of materials. Stating this in another form, 1 cubic foot per second of water moved 160.6 cubic yards of material in 24 hours. The capacity of the pump was 18.67 cubic feet per second, making the daily average of materials moved about 3,000 cubic yards. The average distance over which the material was moved was 600 feet, it being taken from cuts at either end of the embankment site. It required about 300 working days to complete the work, and the unit price per cubic yard was 20 cents.

SILVER LAKE DAM, LOS ANGELES, CAL.

The conditions surrounding the construction of Silver Lake Dam of the Los Angeles Water Company are somewhat unique in that all the materials for the embankment were taken from that portion of the reservoir site situated below the level of the crest of the dam.

THE FOUNDATION WORK.

In starting the foundation for the dam a trench 6 feet wide was dug full length (see fig. 6, p. 34) along the center axis, extending down to bed rock, in some places a distance of 40 feet. It was necessary to use shoring as shown in the figure to prevent the side walls from caving in. While digging this trench quicksand was encount-

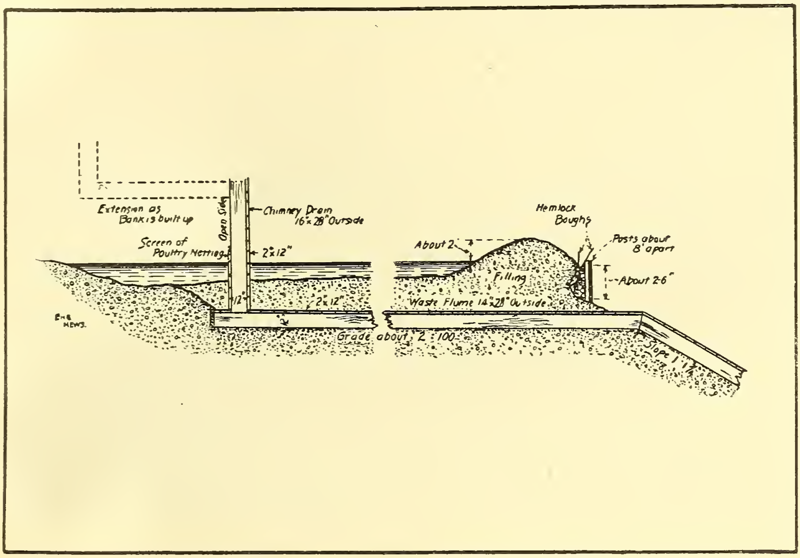

FIG. 37.—View showing brush dikes and chimney drains.

ered and before it was possible to proceed farther it was necessary to drive interlocking steel piling at the bottom of the trench on both sides. This work is shown in progress in figure 38. These piling were 20 feet long and extended down to elevation 365.2, the top of the dam being elevation 450 above sea level. A third and central row of piling was driven down to elevation 358. From the top of the central line of piling, elevation 378 to elevation 416.9, a sheet-steel shield was placed. Concrete was then placed in the trench between the two outer lines of piling, this core being 3 feet in thickness from the 370.7 elevation to the 399-foot elevation and 2 feet in thickness from the latter elevation to elevation 416.9, the top of the steel shield. This core wall extended about 6 to 8 feet above the ground and served as a cut-off to all water seeping beneath the dam.

All loose materials were scraped from the foundation area and the surface plowed before placing any new materials. Selected material was then scraped into embankment form, continuing up to the 408-foot elevation. The earth was placed carefully in layers and kept sufficiently moist so that the tramping of the horses feet would pack it thoroughly. At elevation 408 the materials within reasonable haul gave out and it was necessary to resort to hydraulic methods. The reservoir had some water in it at this stage of the construction and a pumping plant was installed at the water's edge.

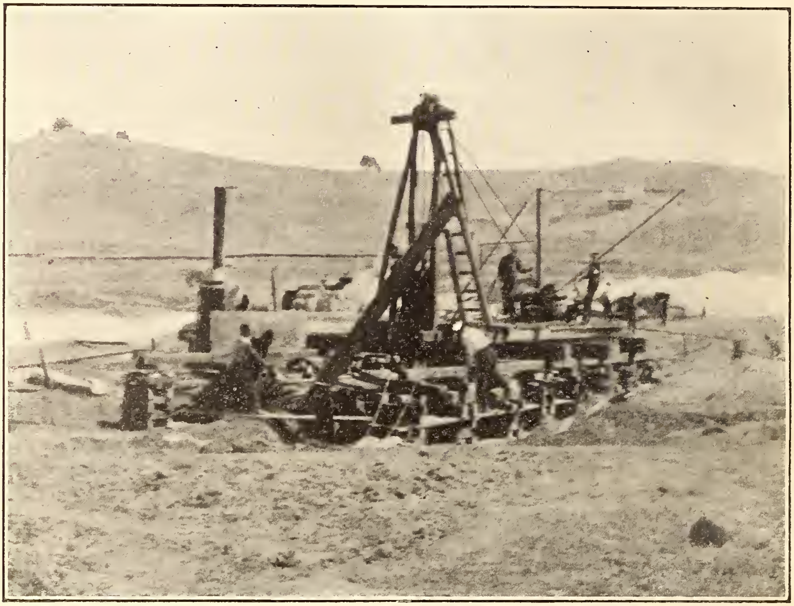

FIG. 38.—Driving interlocking steel sheet piling, Silver Lake Dam, Cal.

TRANSPORTING THE MATERIALS.

The materials were first ground-sluiced down to a sump located near the pumping plant. The water for this purpose was furnished from a regular service pipe to an ordinary fire hose and nozzle (fig. 39). A more effective means was later adopted, as shown in Plate XVII, figure 2. These modified giants were constructed of 4-inch pipe and pivoted on frames made of iron rods, as shown in the figure. Two-inch nozzles were screwed to the ends of these improvised monitors and water supplied to the monitors by a single-stage, centrifugal pump under pressure of about 75 pounds per square inch. The sluiced materials were conveyed down to a sump near the pumping station, shown in figure 39, and from the sump the materials were

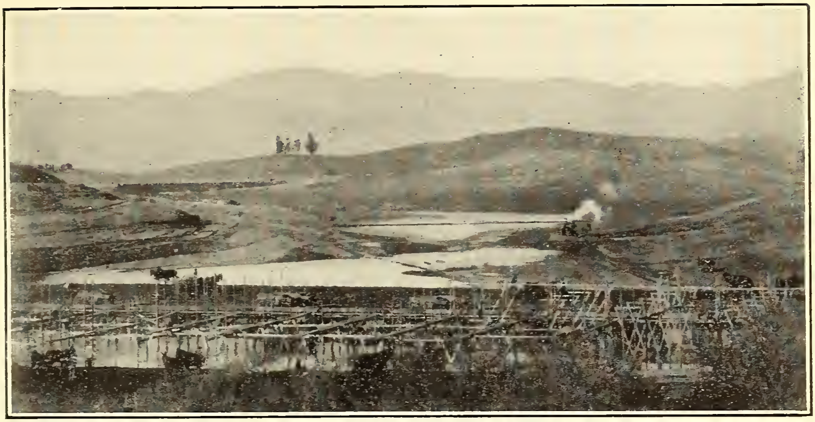

FIG. 1.—FRAMEWORK SUPPORTING DISTRIBUTING PIPES, SILVER LAKE DAM, LOS ANGELES, CAL.

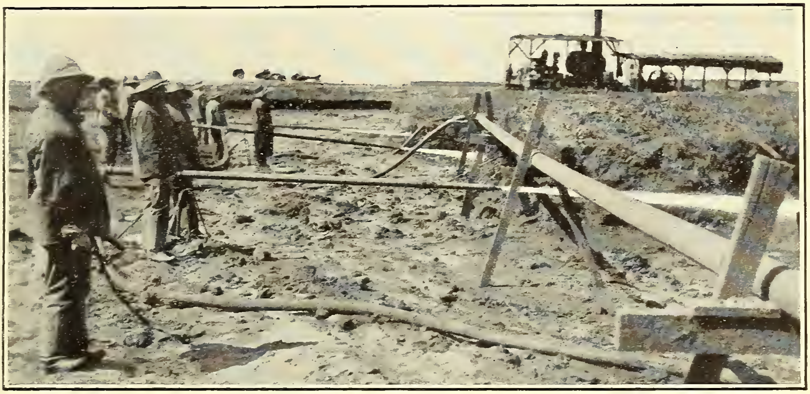

FIG. 2.—IMPROVISED MONITORS OF 4-INCH PIPE AND 2-INCH NOZZLES, USED FOR SILVER LAKE DAM.

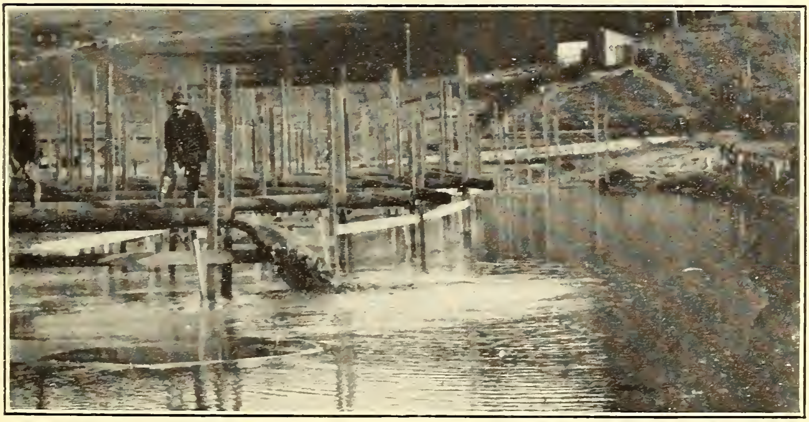

FIG. 3.—DISTRIBUTING MATERIALS UPON EMBANKMENT BY 12-INCH STEEL SLIP-JOINT PIPE, SILVER LAKE DAM.

pumped in two stages through an 8-inch riveted pipe to the dam. The materials consisted mostly of a sandy loam, which was easily sluiced and pumped.

DEPOSITING IN EMBANKMENT.

The pipes discharging the materials upon the dam were 12 inches in diameter, made of sheet iron in 5-foot sections. These distributing pipes were supported by framework erected on top of the dam (Pl. XVII, fig. 1). The pipe was moved over the framework, distributing the materials wherever desired. Levees along the slopes of the dam to retain the sluiced materials were built by wheeled scrapers (Pl. XVII, fig. 1). On the right of the picture the

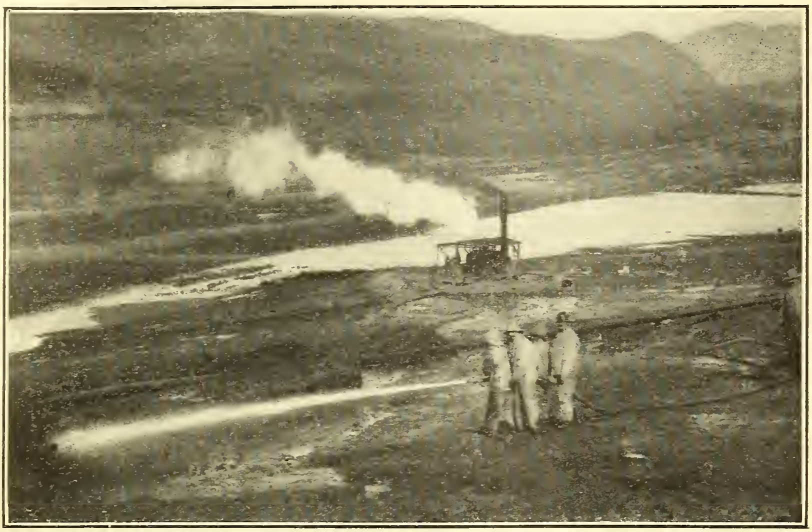

FIG. 39.—Sluicing with fire hose, first used at Silver Lake Dam, Cal. (For later method see Pl. XVII, fig.2).

denuded slopes may be seen in the distance and also the pumping plant. The latter had to be moved farther and farther away as the materials became scarcer. The maximum pumpage was a distance of about 4,000 feet. The distributary pipes delivering the sluiced materials upon the dam are shown in Plate XVII, figure 3. After the levees were constructed along the slopes, connecting levees 18 inches high were built of light earth across the entire top of the dam, dividing it into rectangles. One day's discharge having been placed in a certain section the gates were closed and other gates along the line were opened so that it was possible to distribute the sluiced material at will into any square ready for it. Each rectangle was allowed to drain sufficiently before placing new materials. In this

way a very solid section was obtained as the work progressed and the danger of having a liquid mass in the center eliminated. The dam was further drained by driving 2-inch pipes, having well points and strainers screwed on the end, into the embankment. These pipes, were spaced about 40 feet apart and driven in 75 feet. Water drained from these pipes for a long time after the dam was completed. Plate XVIII, figure 1 shows the dam nearing completion. The central portion is at the drying stage. The men are trimming up the slopes preparatory to filling in the remaining portion of the dam, with wheeled scrapers. Schuyler states that "the greatest amount of seepage from any one of these drainpipes measured 2 gallons per minute, which diminished to one-fourth in a few weeks. These drains were effective in keeping the face of the dam dry and stable." [1]

STREAM CLOSURE BY HYDRAULIC FILL IN MICHIGAN.

The construction of a hydraulic-fill dam in which the closure of a stream figured is well illustrated in the construction of the Croton Dam on the Muskegon River, Mich.[2] This dam was built for the development of power by the Grand Rapids-Muskegon Power Co. A head of 40 feet of water is obtained and 14,400 horsepower is developed. In constructing this dam the river was allowed to run its original course at one side of the work and the closure was affected by narrowing the channel with rock-filled cribs on either side. The final closure of the intervening opening was effected by one or more cribs being floated into position and then filled with stone. The river in the meantime was turned through temporary openings left through the masonry portion of the dam. The sluicing plant was then set at work and a low fill of long slope was made under water upstream from the crib. The sluicing troughs were then diverted to the downstream side of the crib and a permanent embankment put in place. Such temporary closing cribs, when faced with a sluiced fill on the upstream side, were made almost water-tight under a head of 15 feet of water. The water seeping through and accumulating between the temporary and permanent embankments was all taken care of by a 4-inch centrifugal pump running at intervals. While the value of a sluicing plant lies in the cheapness of operation it is also valuable as a means of moving material from a higher to a lower level where it would be very expensive to handle teams on the steep return grade.

The principal fill made with the sluicing plant at the Croton Dam comprised 104,000 cubic yards of sand and gravel taken from the bluff and hill immediately adjoining the end of the embankment into which it was placed.

[1] J. D. Schuyler. Reservoirs for Irrigation, Water Power, and Domestic Water Supply. New York and London, 1908, 2. ed., p. 176.

[2] Engin. News, 58 (1907), No. 17, p. 429.

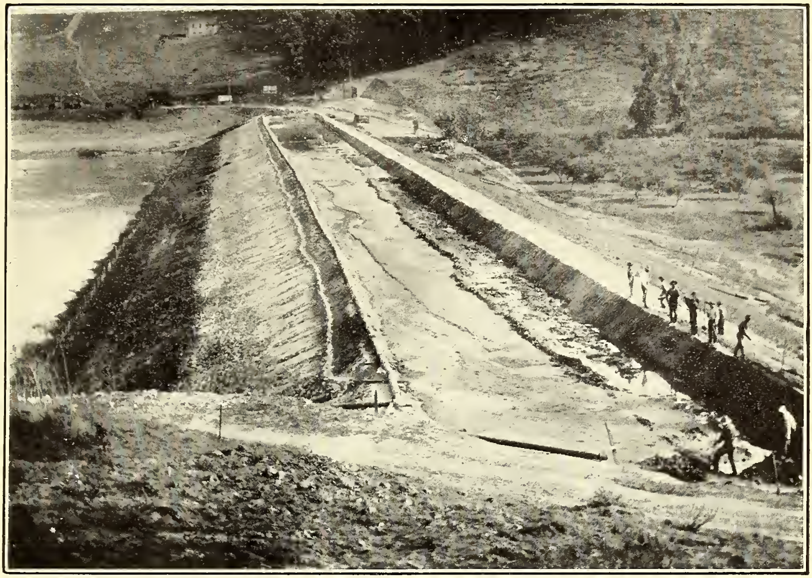

FIG. 1.—FINISHING THE SLOPES PREPARATORY TO FILLING IN CENTRAL PORTION WITH WHEEL SCRAPERS, SILVER LAKE DAM.

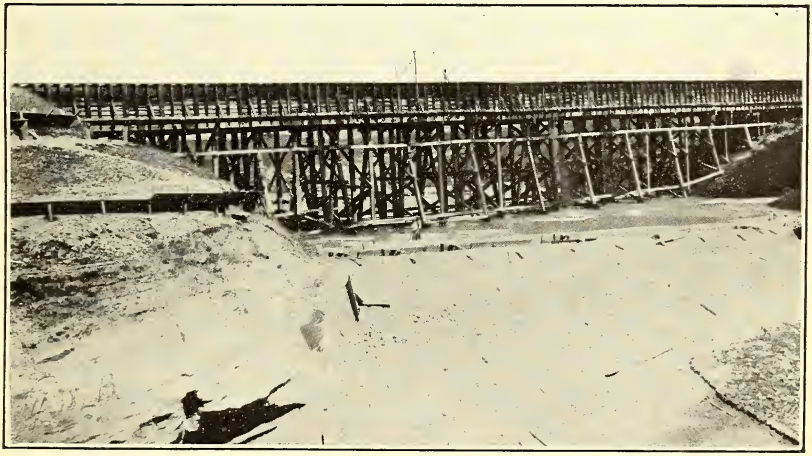

FIG. 2.—PEASLEY GULCH FILL IN COURSE OF CONSTRUCTION. MOVABLE DAMS AT EDGES OF FILL, ALSO V TROUGHS DUMPING MATERIALS.

PUMPING PLANT.

Four 6-inch, one 5-inch, and two 3-inch underwriters, rotary-fire pumps were used, not because of efficiency or desirability, but because they were on hand and were readily adapted for use with motor equipment available. Rotary pumps do not operate well with a suction longer than 8 to 10 feet, and are not adapted for continuous, hard service as on a sluicing plant. Fully one-half the pumps on this work were out of order and undergoing repairs the greater part of the time, due to injuries to the gears and cars. The pump shed, 20 by 24 feet, was built on the river bank and projected over the water so that the suction pipe could be dropped down directly below the pumps.

PIPE LINE.

The force main leading from the pumps was a 10-inch spiral riveted pipe and had gate valves located between each pump connection and beyond the last pump. This main extended along the face of the bluff about 1,000 feet, being successively reduced to 8 inches and 6 inches by wrought-iron pipe with screwed connections. There were tees with 4-inch outlet placed at convenient intervals for laterals and hose connections. Four-inch, iron-body, gate valves were also placed at these tees to control the flow of water. The sluicing work was commenced at the far end of the pipe line where the first closure of the river was to be affected and where the bluff was lowest. By this arrangement the length of the force main was reduced as the work progressed.

TROUGHS.

The black-iron troughing used on this work has been fully described on page 71.

NOZZLES AND GRADES.

The type used mostly was the 4-inch hose nozzle, tapering in 24 inches to an opening of $1\frac{1}{4}$ or $1\frac{1}{2}$ inches inside from the tip. Each nozzle was clamped to a 2 by 10 inch plank about 12 feet long, which in turn was pivoted to a standard similar to the jack used by a wagon-wheel painter, but heavier. While this was a simple device, it served the purpose of the more heavily constructed monitor or "giant" used for high pressure and larger pipes and nozzles. With this arrangement one man handled each nozzle and was assigned one helper for moving hose and keeping the troughs in shape near the nozzle. Where the grades were sufficient no other men were required in the pit. With such an outfit and a pressure of 60 to 80 pounds at the nozzle it was not possible to handle any material that was com-

pacted harder than sand and gravel. With a larger nozzle opening and a pressure of 150 pounds hard clay and loose shale rock may be readily handled. The total height of the hill above the top of the finished embankment was 75 feet. On account of the grades required for the troughs the actual face against which the nozzle worked did not exceed 40 feet. The greatest distance from which materials were moved in the troughs was 800 feet. The grades were generally 8 and 9 per cent, but on some of the larger troughs the grade was reduced to 5 and 6 per cent at the end. With grades less than 6 or 7 per cent there was always trouble, caused by stoppages in the troughs, which required one man to every 50 feet of trough to keep it clear. The nozzles were usually worked in pairs, concentrating their forces at the base of the bluff, and were used in forcing materials along the troughs or channels when the latter became clogged, but not otherwise. No especial headworks were necessary to divert the water to the troughs where the base of the excavation was clay or hardpan, but in sandy and gravelly soils it was necessary to have a converging box or series of boards set up in V-form to start the sluiced materials into the trough.

TRANSPORTING AND DEPOSITING THE MATERIALS.

In the work described the sand and gravel rested on a base of hard, pure clay. The movement of the water cut a slight channel which formed an excellent conveyor for the sluiced materials. This channel deepened very little. As the materials were deposited at the end of the trough a cone made of sand and gravel was formed, from which the water drained away so rapidly that one could walk over the slopes dry shod while the materials were being deposited. In order to further compact the materials in the process of deposition, two lines of troughs were used so as to keep the center of the fill low. Arrangements were made to drain off the water at the far end. In this way there would always be a pool of water and soft material in the center. Sometimes the fill was worked against a temporary dam at the end of the slope so as to prevent the water from passing away too quickly, thus giving the materials more time to settle. The slopes of the finished embankment at 2 to 1 or 3 to 1 were made by setting up boards and using straw to prevent the water from escaping. The straw and boards were moved up the slopes as the work progressed. Toward the end of the fill where the water passing away was more concentrated it was necessary to use brush and cribwork of 2 or 3 inch poles to retain the materials at the proper slopes.

COST.

The following cost data on sluicing at Croton Dam are of interest at this point:

Cost of principal fill at Croton Dam (104,000 cubic yards).

Equipment:		
Two 6-inch underwriters' rotary fire pumps (new)		$840.00
Two 6-inch underwriters' rotary fire pumps (second-hand)		750.00
430 feet, 10-inch No. 16 gage, spiral riveted pipe, at 60 cents per foot, new; second-hand, 45 cents		193.50
400 feet 8-inch wrought pipe and fittings (new)		436.45
414 feet 6-inch, and 120 feet 4-inch wrought pipe fittings		272.00
Material bought second-hand, including all fittings for 10-inch line; 6, 8, and 10 inch fittings for pumps, 150 feet, 4-inch rubber hose and nozzles; 350 feet 30-inch, No. 12 gage troughing, used 2 months on Lyons Dam		800.00
500 feet, No. 12 gage, 30-inch trough		250.00
Pulleys, belting, 3-inch cottonmill hose, and other sundries		200.00
Total		3,741.95
Charging 50 per cent of this item ($1,870.98), to this fill=1.8 cents per cubic yard.		
Labor and supplies:		
Pay roll, June 30 to Sept. 3		3,774.61
Teams—removing stumps and stone, handling trough and trestle timber		248.56
Straw		18.00
Oil, waste, pump repairs, and sundries		118.83
This item adds 4 cents per cubic yard		4,160.00
Power (measured at meter at Big Rapids Dam, 18 miles from Croton):		
July ..... kilowatt hours	56,433	
August ..... kilowatt hours	62,575	
		119,008
June 25–31; Sept. 1–3 ..... kilowatt hours		19,000
		138,008
Deduct for line and transformer losses and for power used for other purposes at Croton		46,008
Total		92,000
92,000 kilowatt hours at 1 cent=$920, which is 0.88 cent per cubic yard.		
Summary (cost per cubic yard of dirt moved):		Cents.
Cost of plant		1.80
Labor and supplies		4.00
Power		.88
Motor rental		.12
Total		6.80

REPLACING A FLUME BY A HYDRAULIC FILL IN CALIFORNIA.

GENERAL LOCATION AND DESCRIPTION.

A new use has been found for hydraulic fills upon some of the western irrigation projects where the canal water must be conveyed across ravines or other depressions. Formerly, wooden flumes supported by trestles of the required height were used for this purpose, but the life of such structures has been found to be short at best, the annual cost of maintenance high, and the risk of loss from breaks or fire very great. Of late years many of such flumes have been replaced by more permanent structures, such as pipe siphons, concrete flumes, or embankments of earth. In many cases hydraulic fills have been used to advantage, the earthen material being sluiced around the supporting timbers in a manner similar to that used in the railway fills previously described, pages 74–80.

There follows a description of the replacing by a hydraulic fill of a high wooden flume across Peasley Gulch on the main canal of the Turlock Irrigation District, about 6 miles southwest of La Grange, Cal. The timber flume had become dilapidated through long years of service, and leaked badly. After considering various plans for a substitute structure it was decided to use the hydraulic fill, building it around the supports of the old flume. The flume was retained in its original position for one season when it was replaced by a reenforced concrete lining. Plate XVIII, figure 2, shows this fill in course of construction.

The fill is located on a stable and impermeable foundation consisting of a clay hardpan intermixed with a stratum of rock. The entire fill comprises 66,000 cubic yards of material. The maximum depth is 70 feet, top width 80 feet, with side slopes 2 to 1, which are riprapped with rock taken from the side of the gulch.

The storm waters of Peasley Gulch are provided for by building a reenforced concrete conduit through the fill. This conduit is 410 feet long and has an inside diameter of 5 feet. The walls are reenforced with ½-inch steel, 68.8 pounds per cubic yard of concrete.

TRANSPORTING THE MATERIALS.

The material from which the fill is made was washed from a sidehill about 500 feet distant from the flume. The material varies in texture, but in general consists of a sandy clay loam underlaid with sandstone and some disintegrated granite. It was washed from the hillside by two hydraulic monitors. (Plate XIX, fig. 1.) These monitors were equipped with 2-inch and 1½-inch nozzles, respectively, and had a pressure of 60 pounds per square inch. Water for the work was pumped from the main canal by two centrifugal pumps, a 7-inch pump supplying one monitor and a 5-inch pump the other. These

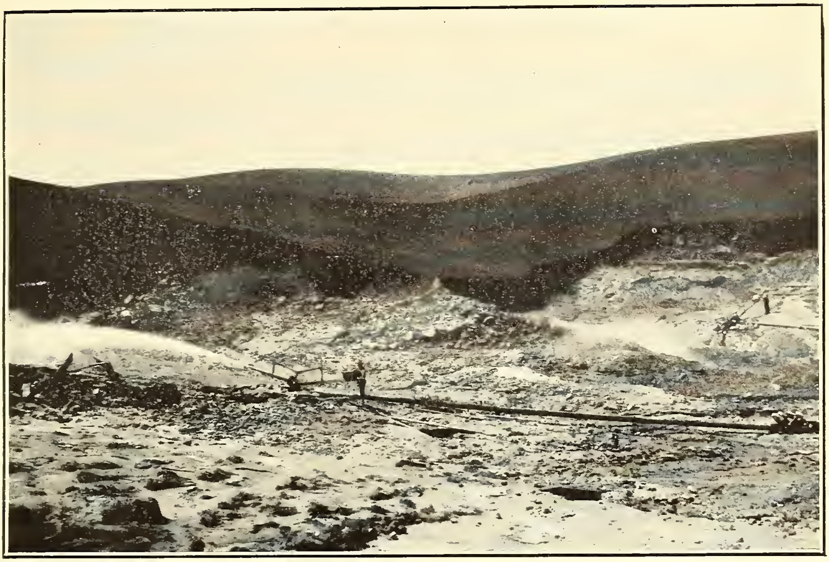

FIG. 1.—SHOWING TWO MONITORS IN ACTION AND RESULTS OF THEIR EROSIVE FORCE, PEASLEY GULCH, CAL.

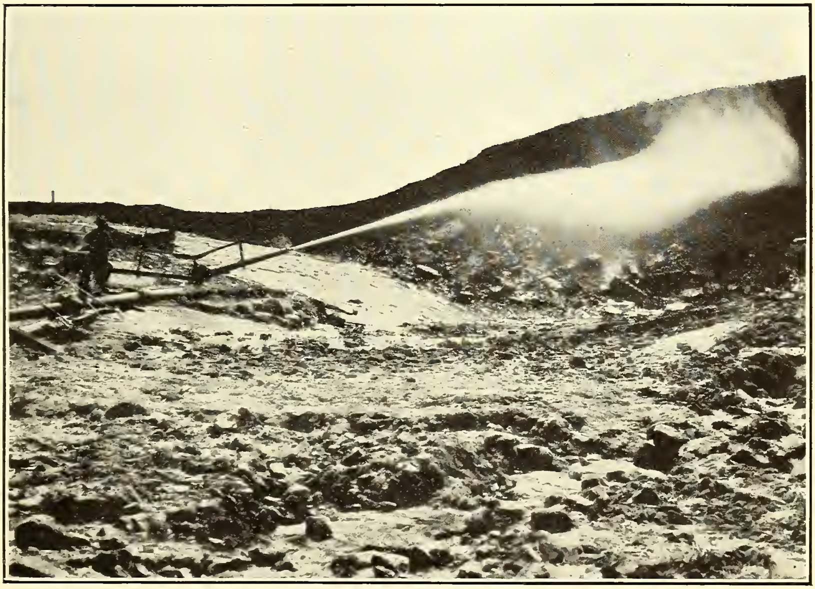

FIG. 2.—MONITOR THROWING STREAM FROM NO. 7 HORIZONTAL, CENTRIFUGAL PUMP, 60 POUNDS PRESSURE, PEASLEY GULCH, CAL.

furnished sluicing heads of 3 and 1½ cubic feet per second, respectively. Power for running the pumps was furnished by an electric motor of 100 horsepower. The actual lift from the water surface in the canal to the monitor nozzle was approximately 15 feet. The effect of the erosive force upon the banks is seen in Plate XIX, figure 2. The sluiced material was transported to the fill by means of a V-shaped timber flume. The latter was built of 2 by 12 timber, with 2-foot sides, 50 feet long and laid on a 5 per cent grade. This was found adequate to carry all the material sluiced by the two monitors. Where the quantity of material moved would not justify an extension of the sluicing flume, the material was sluiced over the ground. This method, however, involves a loss in efficiency. The inspector on the work approximated from several tests that of the materials carried in the sluices about 20 per cent was solids.

DEPOSITING IN EMBANKMENT.

In constructing the fill it was the general plan to keep the sides of the fill from 2 to 3 feet higher than the center, thus preventing the water from draining over the outside slopes. The surplus waters which collected near the center of the fill were carried downward to the concrete conduit by means of a manhole 4 feet square, the timbers of which were carried up about 2 feet in advance of the fill. This outlet was purposely made larger than necessary so that it might be used as a shaft for the passage of men and materials to repair the opening made in the top of the concrete conduits. When the desired height of fill was reached the hole in the conduit was sealed and the shaft filled. The contract price for putting the material in place was 25 cents per cubic yard. The work was done in the spring of 1910. The work has fulfilled all the expectations of the engineers and the board of directors of the district.

COST OF THE WORK.

The cost of this fill is analyzed in the following data prepared from careful records:[1]

Power	$3,000
Powder	430
Labor	7,500
Lumber and equipment (depreciation only)	2,000
Miscellaneous	1,500
Total	14,430

The total yardage in the embankment amounted to 60,290 cubic yards, the average cost to the contractor being 23.77 cents per cubic yard.

[1] Prepared by A. Kempkey, jr., C. E., in charge of the construction.

There are a number of reasons for this comparatively high cost. The fill was small and therefore only a limited quantity of water could be used. This necessitated a long period of construction and a high labor cost. Secondly, there was the added expense due to pumping instead of having a gravity supply. Thirdly, the material varied greatly in character, much of it being very hard and difficult to sluice, and as the suitable portion was found in small quantities many shifts of the monitor were required. Lastly, there were some serious breaks in the canal above the work, which necessitated the shutting down of operations on several occasions, once for a period of two weeks, during which time the contractor lost his entire crew.

THE V-SHAPED FLUME.

The engineer in charge of this work strongly recommended the V-shaped flume in preference to one of rectangular shape for the transporting of the sluiced materials when less than 7 cubic feet per second of water was used. The advantages claimed for it are its adaptability to the use of varying quantities of water without great loss in speed, the stream being confined and having greater transporting power in the smaller volumes; and its ease of construction and the readiness with which the boards may be reversed, placing the top boards in the "V" and the worn boards on top when the original flume becomes unserviceable.

As to the size of materials transported, the engineer further stated that with 4½ cubic feet per second of water and a 5 per cent grade, pieces of light-weight sandstone as large as a man's head, or larger, would readily pass through the flume, while in heavy trap rock, pieces not to exceed one-half this size could be transported

GRADES REQUIRED.

The grade adopted depends upon the character of the material sluiced. In the work at Peasley Gulch the sandy clay and broken hardpan would run readily on a 3½ to 4 per cent grade, while a large part of the sand would block the sluices entirely on a 5 or 5½ per cent grade, unless extreme care were used in manipulation—that is, in the pointing of the monitor so that a proper mixture of material might be run into the sluices.

In a comparison of a flume with a pipe for sluicing purposes the engineer preferred the flume, owing to the increased cost of the pipe, without a corresponding decrease in the wear, also because of the extreme care required to have no sags in the pipe, as these sags are sure to clog when the sluicing is discontinued for a time. The sluicing also must be done with greater caution in the case of the pipe, as large chunks of clay are liable to cause it to become clogged.

THE BASIN METHOD ILLUSTRATED.

MARSHALL LAKE DAM, COLO.

The Marshall Lake Dam in Colorado is an instance where the basin method proved superior to the sluicing method. The reservoir is owned by the Denver Reservoir Irrigation Co. The first 20 feet of the height of the dam was constructed by sluicing the materials in place, and this method was found slow and expensive, probably due to poor management. The material available for construction was mostly shale and the outcrop coal measures. For this reason the engineer in charge did not approve of the use of too much water, such as would produce a supersaturated condition of the material placed, because of its being in the nature of soapstone and having a tendency to slip in large masses. Portions of material did slip to some extent before the dam was finally completed, but from the fact of a scarcity of water for storage the succeeding year and a dry season, the dam had ample opportunity for settlement and drainage. The engineer in December, 1908, stated that this reservoir was in very good condition to hold the storage water. At the beginning of the enlargement of the dam an embankment was constructed by ordinary team methods a short distance below the original dam and some 10 feet higher, the space between the two embankments being filled by the sluicing method. Afterwards dump cars were used for the remainder of the work, the haul varying from 500 to 1,800 feet. The tracks for the cars were placed, as the work progressed, on the completed portions of the dam, and the loose materials were dumped into the water held in trenches built along the top of the dam. The materials were excavated by steam shovels and hauled in dump cars by dinkey engines. For the final upper portion of the dam, trestles were constructed to support the rails and materials were dumped from this trestle into the water. The reservoir was allowed to fill with water as the work progressed, this water being let into and over the portions of the dam as constructed by means of trenches and smaller embankments. This was a novel procedure, but proved effective in this case, the reason being that the materials, being of shale and sandy loam, were drained rapidly and thus formed a very firm embankment as the materials were deposited. Ordinarily, however, it would be very risky to allow water in the reservoir to rise against the newly-made embankment until there was a reasonable certainty that the embankment was sufficiently drained and stable. The materials above the high-water line were settled by the use of pipe and hose, the water being conveyed to the top of the dam by canals along the slopes of the canyon. The specifications stated that the dam was to be constructed by the hydraulic method, the

edges of the slopes to be kept higher than the center of the dam during the sluicing process. The coarser materials were deposited near the slopes of the embankment while the finer materials were placed near the center. All materials not hydraulicked in were puddled in place by dropping the same into trenches filled with water. The total quantity in the dam was about 200,000 cubic yards, of which about 40,000 cubic yards were placed by sluicing, the remainder being puddled in place as previously described.

ARROWHEAD DAM, CALIFORNIA.

The dam of the Arrowhead Reservoir, Little Bear Valley, San Bernardino County, Cal., is an illustration of the basin method somewhat modified, being used in constructing the fill of a dam which has a concrete core wall. The construction of the latter has been previously described. The first step in the building of the earth portion was the building of two track banks 30 feet high across the canyon, one at each toe of the dam. Earth was then brought upon the banks in cars and dumped on the side of the track next to the core wall. The core wall was kept built up to the height of the track banks. Water was pumped from a lake above the upper track bank and directed through nozzles, washing the earth dumped toward the core wall. The loose material was left toward the faces of the dam while the clay and finer material were carried toward the core wall and settled in water against the wall. When the dam between the track banks was built up to such a height that the earth could no longer be washed to the center, new track banks were erected above the first and the work proceeded in the same manner (fig. 40).

The core wall was tested with water as it was built up to see if it was absolutely impervious. If not, it was patched on the outside. The contract price of the earth work was 28½ cents per cubic yard. There were to be 1,300,000 cubic yards in the completed structure.

Figure 41 shows a dam in process of construction by the basin method.

HYDRAULIC FILL UNDER ADVERSE CONDITIONS.

LYONS DAM, GRAND RIVER, MICH.

Hydraulic-fill dams are not always constructed under the most favorable circumstances, as instanced by the Lyons Dam of the Commonwealth Power Co. located on the Grand River at Lyons, Mich. The hydraulic process in this instance was performed under very adverse circumstances, most of the work being done in the winter and so hampered by freezing weather. The hydraulic process was employed because a long haul would otherwise have been necessitated.

The material was taken from the right bank of the river, which consisted of a clay bluff 70 feet high capped with a 10-foot layer of sand and gravel. The clay was so tough and compact that it could not be readily handled and the fill was made almost entirely from the sand and gravel capping. The bluff did not have a very steep slope and consequently several expensive trestles were necessary to carry

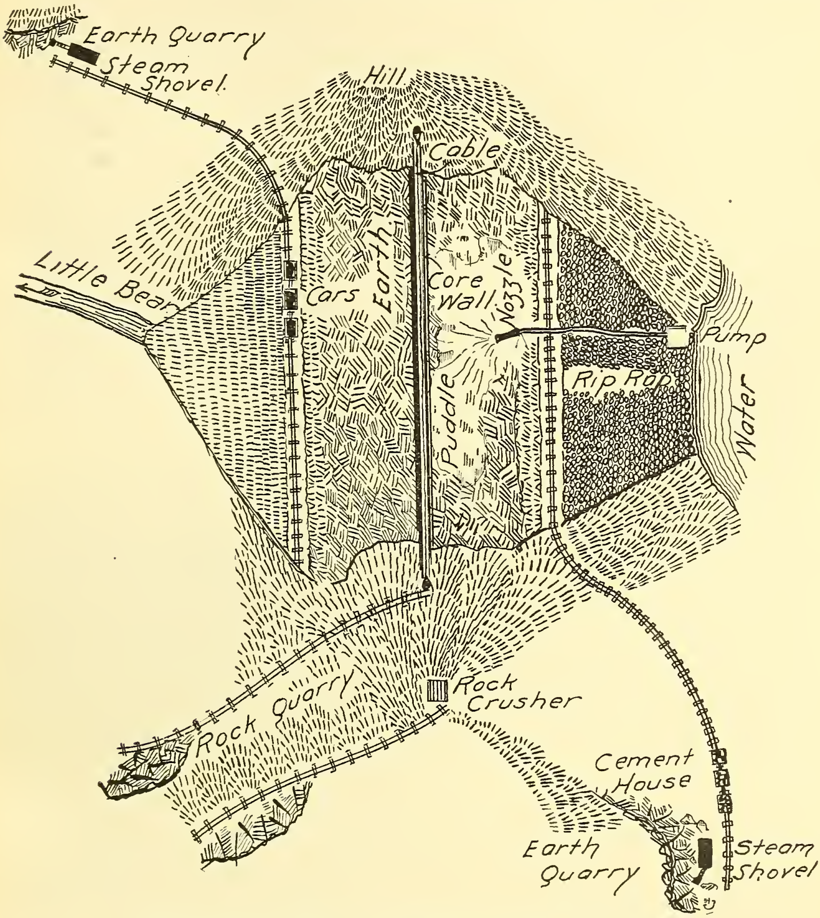

FIG. 40.—Plan of work at Arrowhead Dam, Little Bear Valley, Cal.

the sluice boxes or flumes. These trestles, together with troubles from ice and the scarcity of materials, were the items which added to the cost of construction per cubic yard. The sluicing plant was stopped when the temperature approached zero. When it was again started it was necessary to blast the face of the bluff which had been saturated with water and frozen in for several feet.

COST OF THE WORK.

There were 23,400 cubic yards of material placed at a cost of 33 cents per cubic yard, and it is doubtful whether, even at this price, any other method of moving the materials to the fill would have been less expensive. Below are the items which entered into the cost of construction:

Cost of hydraulic fill of Lyons Dam (23,400 cubic yards).

Labor and materials:	
Setting pumping plant, labor on house for placing pipe, etc	$531.58
Labor at power house	577.20
Labor at pump house	486.60
Sluicing labor, building troughs, and trestles	3,117.50
675 tons coal	1,687.50
Total	6,400.38

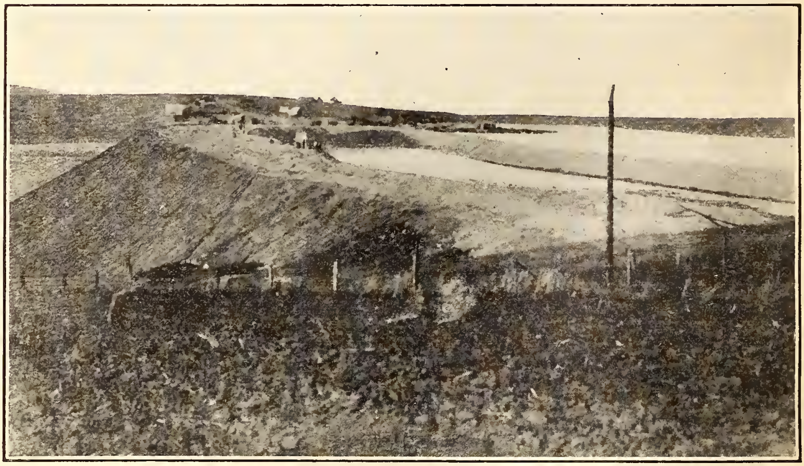

FIG. 41.—Basin method of building an embankment, Lewiston Land & Water Company.

Equipment:		
Two (new) 6-inch and one (second-hand) 5-inch rotary fire pumps	$1,300	
Pipe fittings, troughs, etc	1,200	
Lumber and sundries	500	
		$3,000.00
Less salvage on sale of plant		1,800.00
Balance		1,200.00

Summary:	
Cost of labor per cubic yard of dirt moved	$0.2730
Cost of plant per cubic yard of dirt moved	.0513
Total cost per cubic yard of dirt moved	.3243

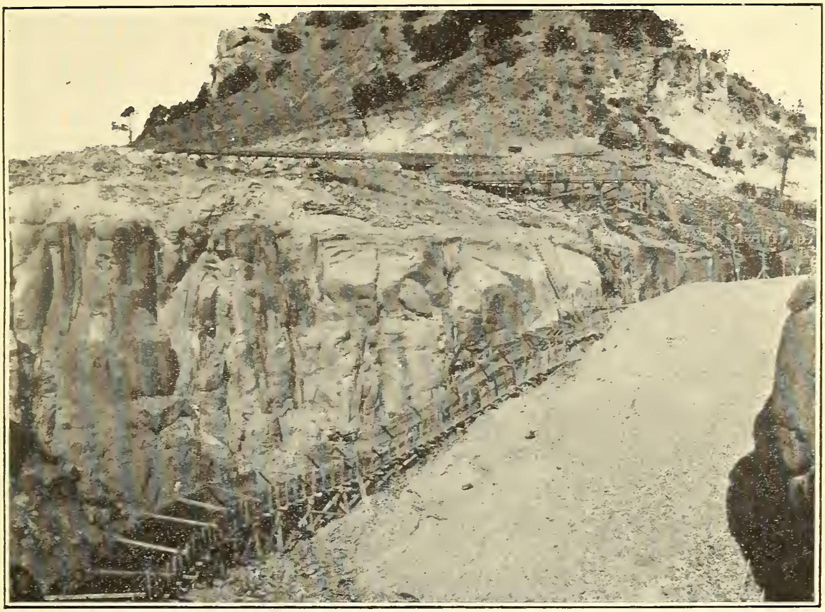

FIG. 1.—FLUME FOR CONVEYING WATER AWAY AFTER MATERIALS HAVE SETTLED. ALSO FLUME CARRYING SLUICED MATERIALS TO DAM, TERRACE LAKE DAM, COLO.

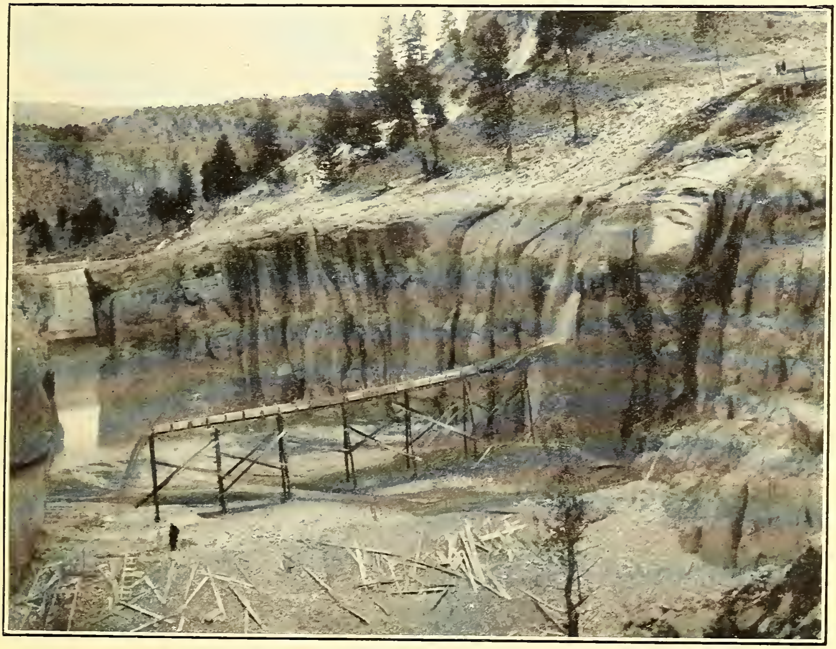

FIG. 2.—DEPOSITING MATERIALS ON OUTER SLOPE, TERRACE LAKE DAM, COLO.

TERRACE DAM, SAN LUIS VALLEY, COLO.

Terrace Dam in the San Luis Valley, Colo., is another instance where conditions were not particularly favorable to the construction of any type of dam. A rock-fill dam was out of the question, owing to the size of dam decided upon; an earth dam was not practicable on account of the earth being intermingled with considerable trap rock of varying sizes. The hydraulic method was the only practicable one by which the materials could be economically placed in embankment, and even then the upper 25 feet of the dam will have to be finished by teams or by methods other than sluicing. This dam was to be 210 feet high when completed. The materials were not of the best, being a glacial drift containing a large number of bowlders, many of which weighed over 100 pounds each, while some were angular trap rock, hard to move, and very destructive to the troughing. The water was brought to the dam site by a canal 9 miles long and having a capacity of 30 cubic feet per second. About 20 cubic feet of water per second was delivered at the penstock. The pressure pipes were 18 inches in diameter near the penstock and after a head of about 50 feet was obtained these pipes were reduced to 15 inches. The nozzles used varied from 4 to 5 inches, depending upon the amount of water available and the number of giants used. It was seldom that more than two giants were used at one time, one being used largely for excavation and tearing up the pits and the other for driving the materials into the flumes. The flumes first used for carrying the materials to the dam were square (Pl. XX, fig. 1) and had timber slabs and poles laid in the bottom for protection. Plate XX, figure 1 shows the opposite side of the canyon, the sluiced materials being deposited on the outer slope. When the work was resumed in the fall of 1908, after a discontinuance of several months, semicircular flumes $2\frac{1}{2}$ feet wide and 18 inches deep, laid on a 4 per cent grade, were used. The main part of the waterway in these flumes is of one-eighth-inch steel and lined with steel plates 12 inches wide and five-eighths inch thick. The material was transported about 1,000 feet prior to December, 1908, after which the distance averaged one-half mile. The pressure head in December, 1908, was 200 feet, which of course was reduced as the construction work proceeded. The flume was elevated several times, so that the minimum head ultimately would be 125 feet. The maximum amount of material placed in the dam during any one month was about 30,000 yards, the effective run per day being 12 hours. The maximum amount of solid material carried was about 10 per cent of the amount of water. The cost of sluicing per month was between $5,000 and $6,000, making the unit cost 16 to 20 cents per cubic yard.

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